U. S. Department
of Transportation
**United States
Coast Guard**

Report of the International Ice Patrol in the North Atlantic

1994 Season
Bulletin No. 80
CG-188-49

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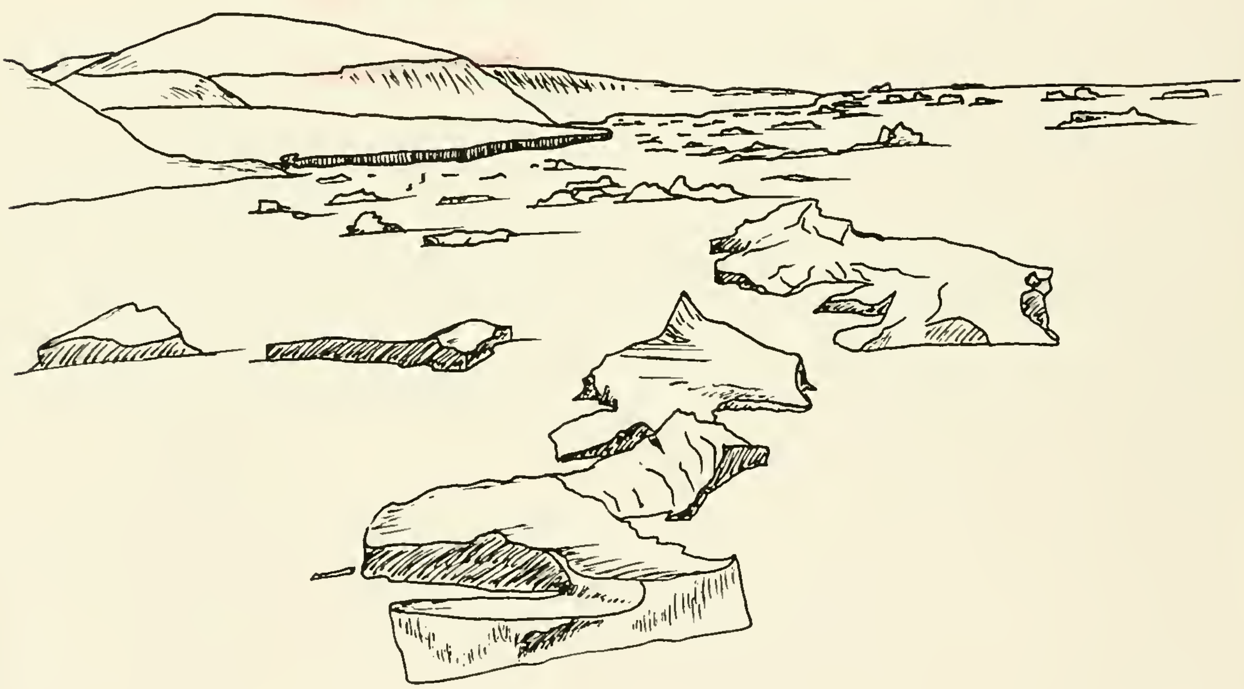

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Bulletin No. 80

REPORT OF THE INTERNATIONAL ICE PATROL
IN THE NORTH ATLANTIC

Season of 1994

CG-188-49

Forwarded herewith is Bulletin No. 80 of the International Ice Patrol, describing the Patrol's services, ice observations and conditions during the 1994 season.

J. A. CREECH
Captain, U.S. Coast Guard
Acting Chief,
Office of Navigation Safety
and Waterway Services

International Ice Patrol 1994 Annual Report

Contents

Introduction

This is the 80th annual report of the International Ice Patrol (IIP). It contains information on Ice Patrol operations, environmental conditions, and ice conditions for the 1994 IIP season. The U.S. Coast Guard conducts the Ice Patrol in the North Atlantic under the provisions of U.S. Code, Title 46, Sections 738, 738a through 738d, and the International Convention for the Safety of Life at Sea (SOLAS), 1974. The IIP is supported by 17 member nations (Appendix A). It was initiated shortly after the sinking of the RMS TITANIC on April 15, 1912 and has been conducted seasonally since that time.

Commander, International Ice Patrol (CIIP) is under the operational control of Commander, Coast Guard Atlantic Area. CIIP directs the Ice Patrol from its Operations Center in Groton, Connecticut. IIP receives iceberg location reports from ships and planes transiting its patrol area and conducts aerial Ice Reconnaissance Detachments (ICERECDETS) to survey the southeastern, southern, and southwestern regions of the Grand Banks of Newfoundland for icebergs. IIP analyzes ice and environmental data and employs an iceberg drift and deterioration model to produce twice-daily iceberg warnings which are broadcast to mariners as ice bulletins and facsimile charts. IIP also responds to requests for iceberg information. IIP's ICERECDETS were based in ST. Johns, Newfoundland, Canada during the 1994 season.

Vice Admiral Paul A. Welling was Commander, Atlantic Area, until June 24, 1994, when he was relieved by Vice Admiral James M. Loy. Captain Alan D. Summy was Commander, International Ice Patrol until July 20, 1994, when he was relieved by CDR Ross L. Tuxhorn.

Summary of Operations, 1994

The 1994 IIP year (October 1, 1993 - September 30, 1994) marked the 80th anniversary of the International Ice Patrol, which was established February 7, 1914. IIP's operating area is enclosed by lines along 40°N, 52°N, 39°W, and 57°W (Figure 1).

IIP's first preseason aerial ICERECDET of the year departed on January 24. The 1994 IIP season was opened on February 23 and from this date until September 1, 1994, an ICERECDET operated from Newfoundland every other week. The season officially closed on September 2, 1994.

IIP's Operations Center in Groton, Connecticut analyzed the iceberg sighting information from the ICERECDETs, ships, Atmospheric Environment Service (AES) of Canada sea ice/iceberg reconnaissance flights, and other sources. Air reconnaissance consisting of Coast Guard (IIP), Other Air Recon, and Canadian AES was the major source of iceberg sighting reports this season, accounting for 65% of the icebergs sighted in 1994 (Table 1). Ships provided 19.5% of the iceberg sightings received by IIP in 1994. Their continued active participation indicates the value that they place on IIP's service. In 1994, 303 ships of 45 different nations provided ice information to IIP. This demonstrates the number of nations using the services of and contributing to IIP far exceeds the 17 member nations underwriting IIP under SOLAS 1974. Appendix B lists the ships that provided iceberg sighting reports, including reports of radar targets. In Appendix B, a single report may contain multiple targets.

The largest contributor of air reconnaissance reports was Atlantic Airways. Their reports account for nearly all of the category "Other Air Recon" on Table 1. Atlantic Airways is a private company that provides aerial reconnaissance services for the Canadian De-

Table 1
Sources of All Sightings
Entered into IIP's Drift Model

Sighting Source	Percent of Total
Coast Guard (IIP)	11.3
Other Air Recon	34.5
Canadian AES	19.2
BAPS	13.9
Ships	19.5
Other	1.6

Table 2
Sources of All Sightings
South of 45°N

Sighting Source	Percent of Total
Coast Guard (IIP)	31.0
Other Air Recon	17.4
Canadian AES	8.2
BAPS	0
Ships	43.4
Other	0

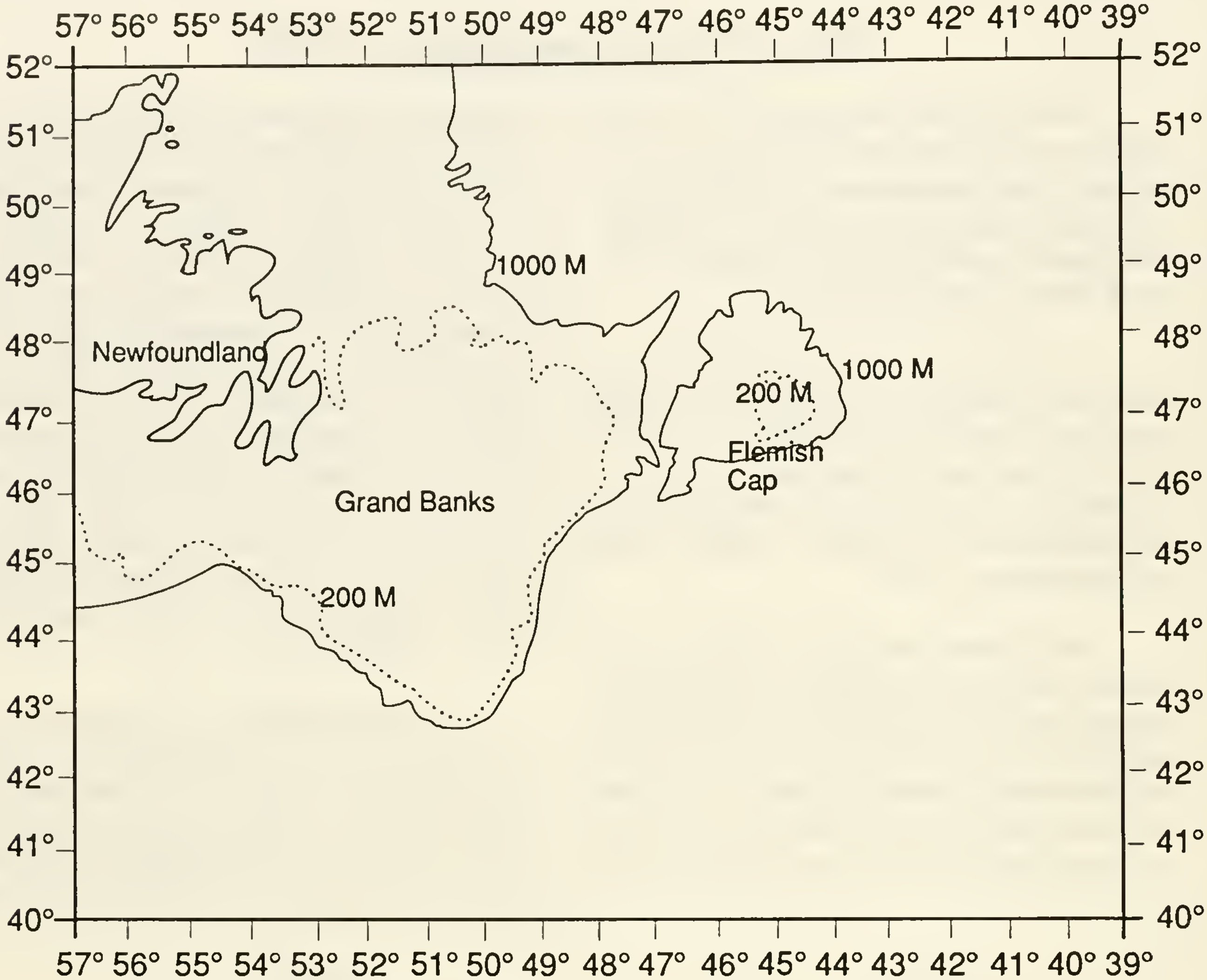

Figure 1
International Ice Patrol's Operation Area showing bathymetry of the Grand Banks of Newfoundland

partment of Fisheries and Oceans (DFO) year round, and for AES June through December. DFO flights, which are designated to monitor the activities of fishing vessels, frequently carry them to areas with high iceberg concentrations. The next largest contribution to the air reconnaissance total is from IIP ICERECDETs. IIP flights concentrate on defining the boundaries of the iceberg distribution. These are typically areas of low iceberg concentrations. Table 2 shows the increased relative contribution of the IIP flights near the limits. BAPS sightings are icebergs detected north of 52°N primarily by AES reconnaissance. These are passed to IIP by AES as the icebergs cross into the Ice Patrol operating area. AES acquired and relayed to IIP iceberg information obtained during sea ice reconnaissance flights and a few flights dedicated solely to iceberg reconnaissance.

During 1994, the IIP Operations Center received a total of 9446 target sightings within its operations area which were entered into IIP's drift model. This is comparable to the 8058 target sightings during 1993. The 9446 targets entered into IIP's drift model do not represent all of the targets reported to IIP.

Sightings of targets outside IIP's Area of Responsibility (AOR) were not entered into the model. Most of these were far to the north of IIP's AOR in areas not covered by IIP's model. Coastal iceberg sightings were also screened, and only those with the potential to drift into the transatlantic shipping lanes were entered into the IIP model.

Table 3 includes icebergs detected south of 48°N plus the number of icebergs which were predicted to drift across 48°N for each month of 1994. During the 1994 ice year, an estimated 1765 icebergs drifted south of 48°N; whereas, during 1993, 1753 icebergs had drifted south of 48°N.

Table 3
Number of Icebergs South of 48°N

Number of icebergs South of 48°N during 1994.

	Ice Year 1994
OCT	0
NOV	0
DEC	0
JAN	0
FEB	79
MAR	529
APR	208
MAY	377
JUN	387
JUL	161
AUG	24
SEP	0
Total	1765

IIP classifies the severity of the ice seasons based on the historic iceberg counts of its entire 80 year history. Ice years with fewer than 300 icebergs crossing 48°N are defined as light ice years; those with 300 to 600 crossing 48°N as moderate; and those with more than 600 crossing 48°N as extreme (Appendix C). 1994 was an extreme year for iceberg conditions.

The 1994 season was the second year that IIP used its iceberg Data Management and Prediction System (DMPS). This system, which is nearly identical to the iceBerg Analysis and Prediction System (BAPS) used at the Canadian Ice Centre, Ottawa, combines an iceberg drift model with a deterioration model. The model uses wind, ocean current, and iceberg size data to predict the movement and deterioration of all icebergs entered into DMPS. The drift prediction model uses a historical current data base which is modified weekly using satellite-tracked ocean drifting buoy data, thus taking into account local, short-term, current fluctuations. Murphy and Anderson (1985) described and evaluated the drift model.

The iceberg deterioration model uses daily sea surface temperature and wave height information from the U.S. Navy Fleet Numerical Meteorological and Oceanography Center (FNMOC) to predict the melt of icebergs. Anderson (1983) and Hanson (1987) described the IIP deterioration model in detail.

Twelve satellite-tracked ocean drifting buoys were deployed to provide current data for IIP's iceberg drift model during the 1994 season. The buoys are similar in design to the World Ocean Circulation Experiment (WOCE) and were equipped with surface temperature sensors and a drogue centered at 50 meters. Drift data from the buoys are discussed in the IIP 1994 Drifting Buoy Atlas, which is available upon request.

During the 1994 season, IIP successfully deployed 110 Air-deployable eXpendable BathyThermographs (AXBTs), which measure temperature with depth and transmits the data back to the aircraft. Temperature data from the AXBTs were sent to the Canadian Meteorological and Oceanographic Center (METOC) in Halifax, Nova Scotia, Canada, the U.S. Naval Atlantic Meteorology and Oceanography Center (NLMOC) in Norfolk, Virginia, and FNMOC for use as inputs into ocean temperature models. IIP directly benefits from AXBT deployments by having improved ocean temperature data provided to its iceberg deterioration model. IIP also provided weekly drifting buoy sea surface temperature (SST) and drift histories to METOC and NLMOC for use in water mass and SST analyses. Canada's Maritime Command/ Meteorological and Oceanographic Centre provided the AXBT probes for IIP use. IIP greatly appreciates the valuable support given by METOC for this program. The data collected significantly increases regional knowledge of circulation patterns and improves the capability to predict iceberg deterioration.

On April 15, 1994, IIP paused to remember the 82nd anniversary of the sinking of the RMS TITANIC. During an ice reconnaissance patrol, two memorial wreaths were placed near the site of the sinking to commemorate the nearly 1500 lives lost. On that same day, IIP committed the cremated remains of Mrs. Ruth Becker Blanchard, (a Titanic survivor) to the sea near the disaster site.

Iceberg Reconnaissance and Communications

During the 1994 Ice Patrol year, 139 aircraft sorties were flown in support of IIP. Of these, 54 were transit flights to St. John's, Newfoundland, IIP's base of operations since 1989, and 70 were ice observation flights made to locate the southwestern, southern, and southeastern limits of icebergs. Fifteen logistics flights were required to support and maintain the patrol aircraft. Tables 4 and 5 show aircraft use for the 1994 ice year.

IIP's aerial ice reconnaissance was conducted with SLAR and FLAR-equipped U.S. Coast Guard HC-130H and a SLAR-equipped HU-25B aircraft. The HC-130H aircraft used on Ice Patrol are based at Coast Guard Air Station Elizabeth City, North Carolina, and HU-25B aircraft at Coast Guard Air Station Cape Cod, Massachusetts.

This was the second operational year for the FLAR. The operational experience gained in 1994 show the SLAR/FLAR combination to be a vast improvement in iceberg identification over the SLAR only system (See Appendix D).

IIP schedules aerial iceberg surveys every other week rather than every week. This is due to the ability of the SLAR and FLAR to detect and differentiate icebergs in all weather, combined with use of the iceberg drift and deterioration computer model to track icebergs in between sightings.

The HC-130H 'Hercules' aircraft has been the primary platform for Ice Patrol aerial reconnaissance since 1963, while the HU-25B has been used since 1988. The extent of the iceberg distribution throughout most of the 1993 season required the use of the HC-130 rather than the HU-25B. Thus, the HU-25B logged significantly fewer IIP flight hours than the HC-130. The total number of flight hours

Table 4
Aircraft Used During The 1994 IIP Year

Sorties

Aircraft	Transit	Patrol	Research	Logistics	Total
HC-130H	50	63	0	15	128
HU-25B	4	7	0	0	11
Total	54	70	0	15	139

Flight Hours

Aircraft	Transit	Patrol	Research	Logistics	Total
HC-130H	135.2	386.4	0	31.5	553.1
HU-25B	5.5	18	0	0	23.5
Total	140.7	404.4	0	31.5	576.6

Table 5
Iceberg Reconnaissance Sorties

MONTH	HU-25B SORTIES	HU-25B FLIGHT HOURS	HC-130 SORTIES	HC-130 FLIGHT HOURS	TOTAL SORTIES	TOTAL FLIGHT HOURS
JAN	0	0	1	7.4	1	7.4
FEB	0	0	4	20.6	4	20.6
MAR	0	0	9	56.7	9	56.7
APR	0	0	7	45.2	7	45.2
MAY	0	0	13	81.7	13	81.7
JUN	0	0	12	68.8	12	68.8
JUL	0	0	8	48.4	8	48.4
AUG	0	0	7	43.4	7	43.4
SEP	7	18.0	2	14.2	9	32.2
TOTAL	**7**	**18.0**	**63**	**386.4**	**70**	**404.4**

Table 6
Iceberg and SST Reports

Number of ships furnishing Sea Surface Temperature (SST) reports	33
Number of SST reports received	201
Number of ships furnishing ice reports	303
Number of ice reports received	1105
First Ice Bulletin	231200Z FEB 94
Last Ice Bulletin	021200Z SEP 94
Length of Season (Days)	192

decreased slightly from 667.0 hours in 1993 to 576.6 hours in 1994. The number of sorties decreased from 154 in 1993 to 139 in 1994.

Each day during the ice season, IIP prepared and distributed ice bulletins at 0000Z and 1200Z to warn mariners of the southwestern, southern, and southeastern limits of icebergs. U. S. Coast Guard Communications Station Boston, Massachusetts, NMF/NIK, and Canadian Coast Guard Radio Station St. John's Newfoundland/VON were the primary radio stations responsible for the dissemination of the ice bulletins. In addition the 0000Z and 1200Z ice bulletin and safety broadcasts were delivered over the INMARSAT-C SafetyNet via the AOR-W satellite. Other transmitting stations for the bulletins included METOC Halifax, Nova Scotia/CFH, Canadian Coast Guard Radio Station Halifax/VCS, Radio Station Bracknel, UK/GFE, and U.S. Navy LCMP Broadcast Stations Norfolk/NAM, Virginia, and Key West, Florida.

IIP also prepared a daily facsimile chart, graphically depicting the limits of all known ice, for broadcast at 1600Z and 1810Z daily. The 1810Z broadcast was added this year to give the mariner a second opportunity to receive the facsimile chart. In addition, the facsimile chart was placed on Comsat Corp's INMARSAT-A FAXMAIL Server for receipt at sea. Both facsimile chart initiatives were in response to recent user survey. U. S. Coast Guard Communications Station Boston assisted with the transmission of these charts. Canadian Coast Guard Radio Station St. John's/VON and U.S. Coast Guard Communications Station Boston/NIK provided special broadcasts as required.

As in previous years, International Ice Patrol requested that all ships transiting the area of the Grand Banks report ice sightings, weather, and sea surface temperatures via Canadian Coast Guard Radio Station St. John's/VON or U. S. Coast Guard Communications Station Boston/NIK. Response to this request is shown in Table 6. Appendix B lists all contributors. IIP received relayed information from the following sources during the 1994 ice year: Canadian Coast Guard Marine Radio Station St. John's VON; Canadian Coast Guard Vessel Traffic Centre/Ice Operations St. John's; Ice Centre Ottawa; Canadian Coast Guard Marine Radio Halifax/VCS; ECAREG Halifax, Canada; U.S. Coast Guard Communications and Master Station Atlantic, Chesapeake, Virginia; and U.S. Coast Guard Automated Merchant Vessel Emergency Response/Operations Systems Center, Martinsburg, WV. Commander, International Ice Patrol extends a sincere thank you to all stations and ships which contributed reports. The vessel providing the most reports was the M/V Cast Polar Bear, a Croatian flag vessel.

Canadian Forces 727th Communications Squadron/St. John's Military Radio served as the primary facility for air ground communications, and the 726th Communications Squadron/Halifax Military Radio was the secondary facility.

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Discussion of Ice and Environmental Conditions

Background

The Labrador Current is the main mechanism transporting icebergs south to the Grand Banks. Its relatively cold water keeps the deterioration of icebergs in transit to a minimum.

The wind direction and intensity along the Labrador and Newfoundland coasts has a significant effect on iceberg drift. Icebergs can be accelerated along or driven out of the main flow of the Labrador Current (Figure 2). Departure from the Labrador Current normally slows their southerly drift and, in many cases, speeds up their rate of deterioration.

Sea ice protects the icebergs from wave action, the major agent of iceberg deterioration. If sea ice extends to the south and over the Grand Banks of Newfoundland, the icebergs will be protected longer as they drift south. When the sea ice retreats in the spring, large numbers of icebergs will be left behind on the Grand Banks. If this time of sea ice retreat is delayed by below normal air temperatures, the icebergs will be protected longer, and a longer than normal ice season can be expected. Less southerly sea ice extent or above normal air temperatures may result in a shorter season.

Sea ice can impede the transport of icebergs. The degree depends on the concentration of the sea ice and the size of the iceberg. The greater the sea ice concentration, the greater the affect on iceberg drift. The larger the iceberg, the less sea ice affects its drift.

The 1994 Season

Figures 3 to 14 compare the sea ice edge during the 1994 ice year to the mean sea ice edge. The mean sea ice edges were taken from Cote (1989) and represent a 25 year average (1962-1987). The ice edge (sea ice concentration > = 1/10) is taken from the daily Ice Analysis from Ice Centre, Ottawa.

Figures 15 to 29 show the Ice Patrol Limits of All Known Ice (LAKI) and the daily sea ice edge on the 15th and 30th day of each month during the ice season. The ice edge is taken from the Ice Centre, Ottawa FICN2 daily product. The edge plotted is a coarse numeric representation of daily Ice Analysis. These figures show the distribution of all icebergs and radar contacts tracked by IIP's model at the given times. Numerals are given for clarity for those one-degree squares where six or more targets are located.

The following is a discussion of the environmental conditions. The meteorological and sea ice information is taken from the Ice Centre Ottawa Thirty Day Ice Forcast for Eastern Canadian Waters.

December

The mean air temperatures were about 1-2°C above normal along the Labrador Coast. The above normal temperatures were driven by predominating southwesterly winds. Despite the high temperatures and southerly winds, the sea ice growth was about 1 week ahead of normal (Figure 5). No icebergs crossed 48°N in December.

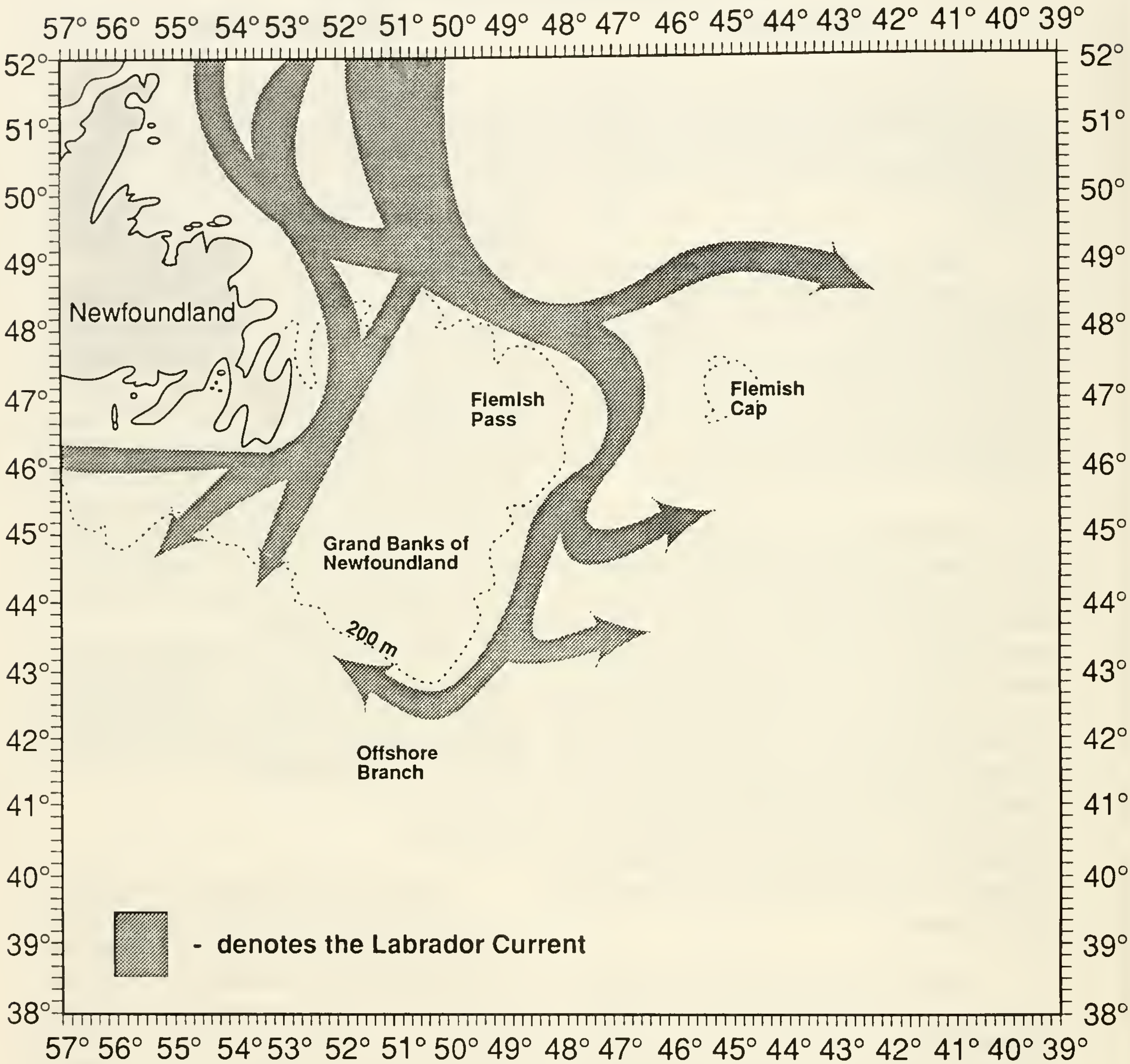


Figure 2
The Labrador Current, the main mechanism for transporting icebergs South to the Grand Banks.

January and February

Sea ice growth along the Labrador Coast and in East Newfoundland waters was about 2-4 weeks ahead of normal (Figures 6 and 7). Air temperatures were 2-8°C below normal due to a persisting northwesterly flow. No icebergs crossed 48°N in January; 79 icebergs crossed 48°N in February. The 1994 ice season opened on 23 February with the southern LAKI near 45°N (Figure 15). The southern extent of the LAKI at the end of February was 44°N (Figure 16).

March and April

During March and April, below normal air temperatures (1-4°C) and northwesterly winds maintained a greater than normal sea ice extent (Figures 8 and 9). The southern extent of the LAKI during this period was 41°N (Figures 17-20). There were 529 and 208 icebergs south of 48°N in March and April, respectively.

May and June

The air temperatures during May and June were near to slightly below normal. However, sea ice destruction was delayed due to a weak and variable wind flow. As a result, greater than normal sea ice extents persisted (Figures 10 and 11). The southern extent of the LAKI during May and June was 42°N (Figures 21-24). There were 377 and 387 icebergs south of 48°N in May and June respectively.

July, August, and September

The air temperatures during July and August were near to slightly above normal. The sea ice retreated to above 60°N (Figures 12 and 13). The weak windflow persisted and slowed iceberg destruction. The southern extent of the LAKI had retreated to 45°N by the end of July (Figure 26). By the end of August, the LAKI had retreated to 48°N and the ice season was closed on 02 September. There were 161 and 24 icebergs south of 48°N in July and August, respectively.

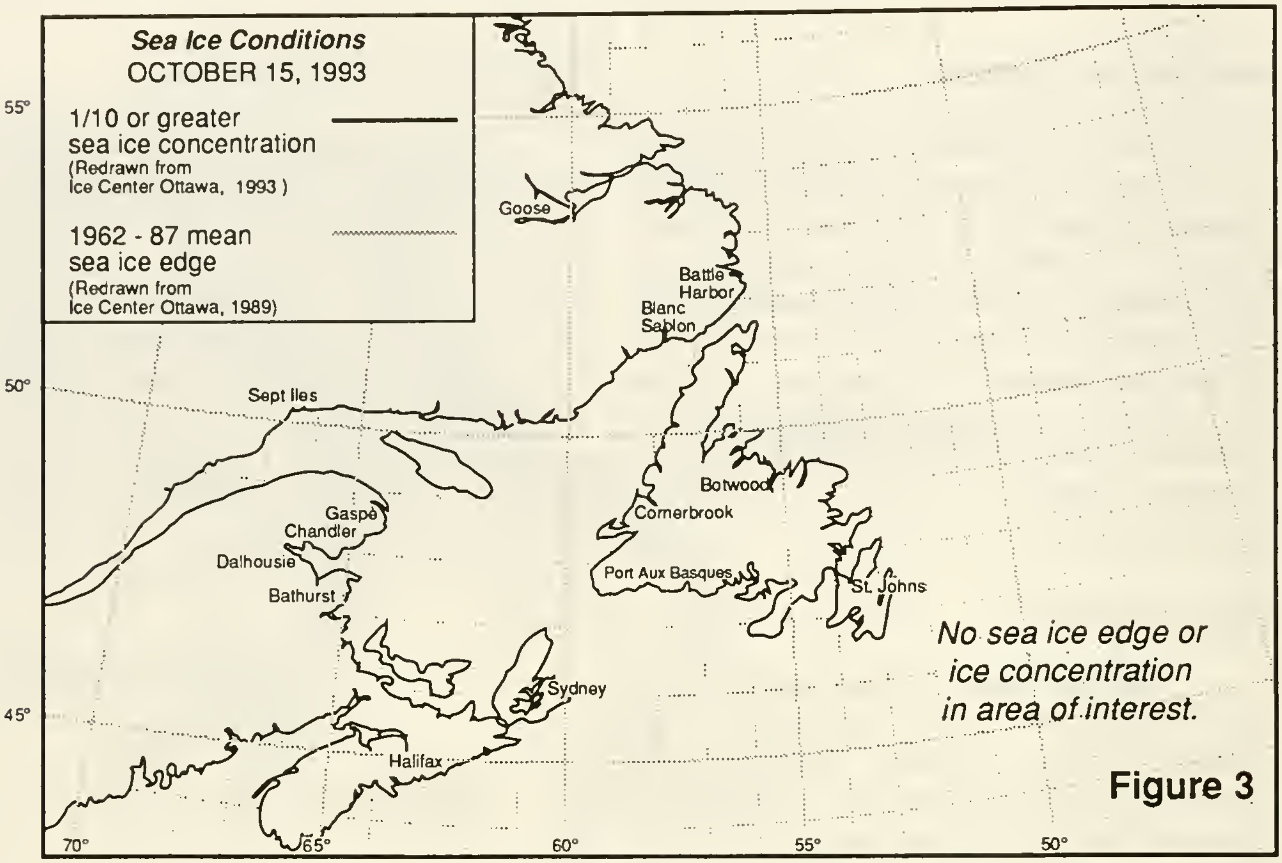


Figure 3

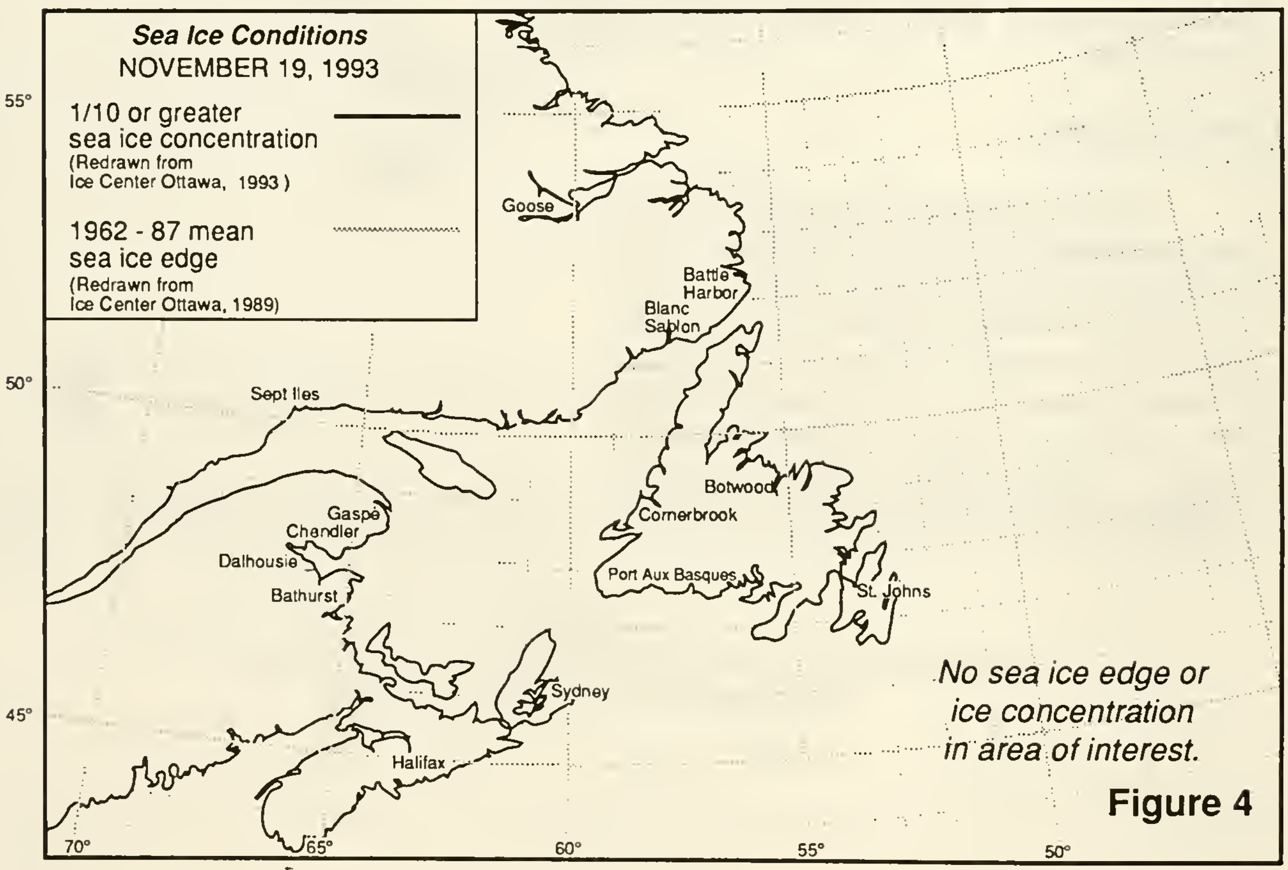


Figure 4

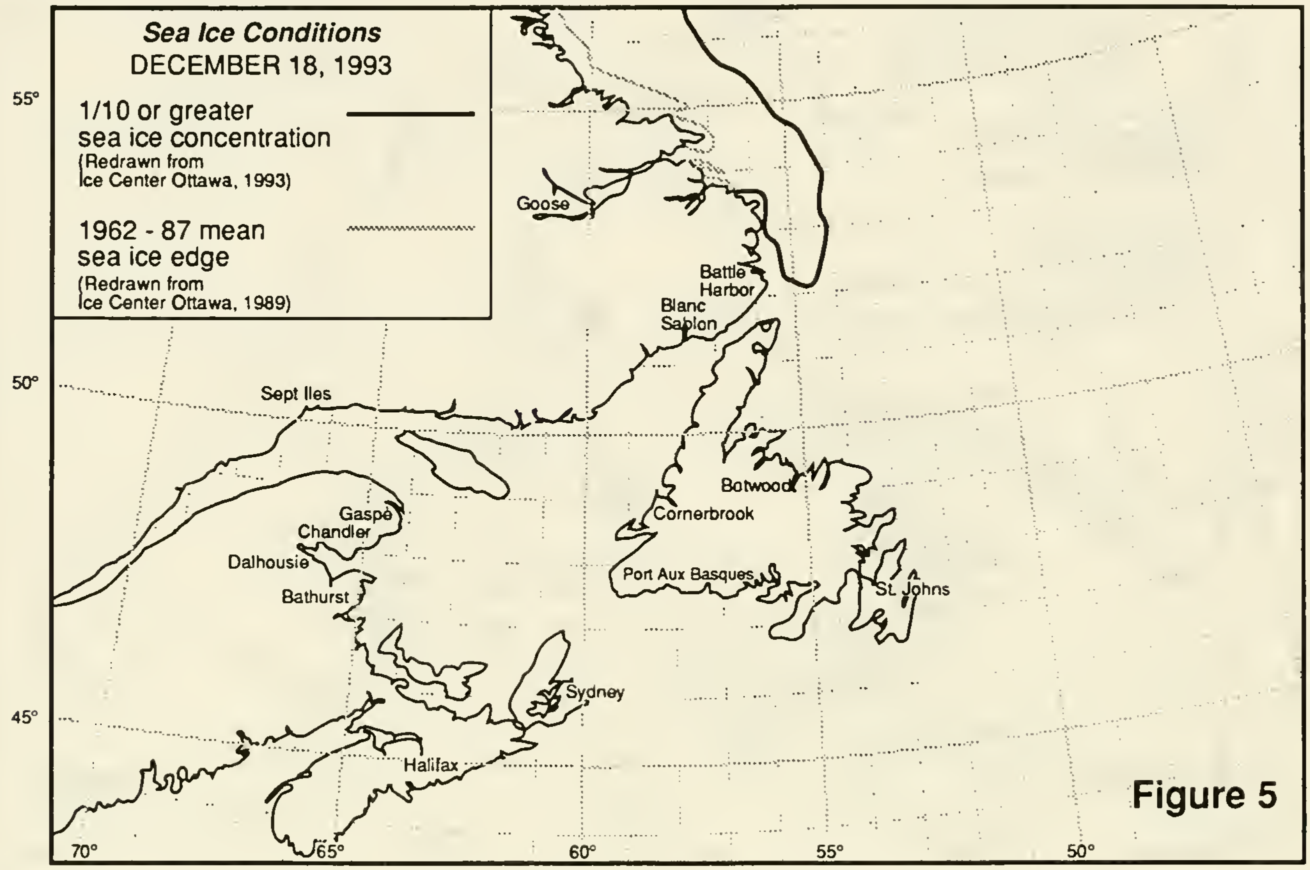


Figure 5

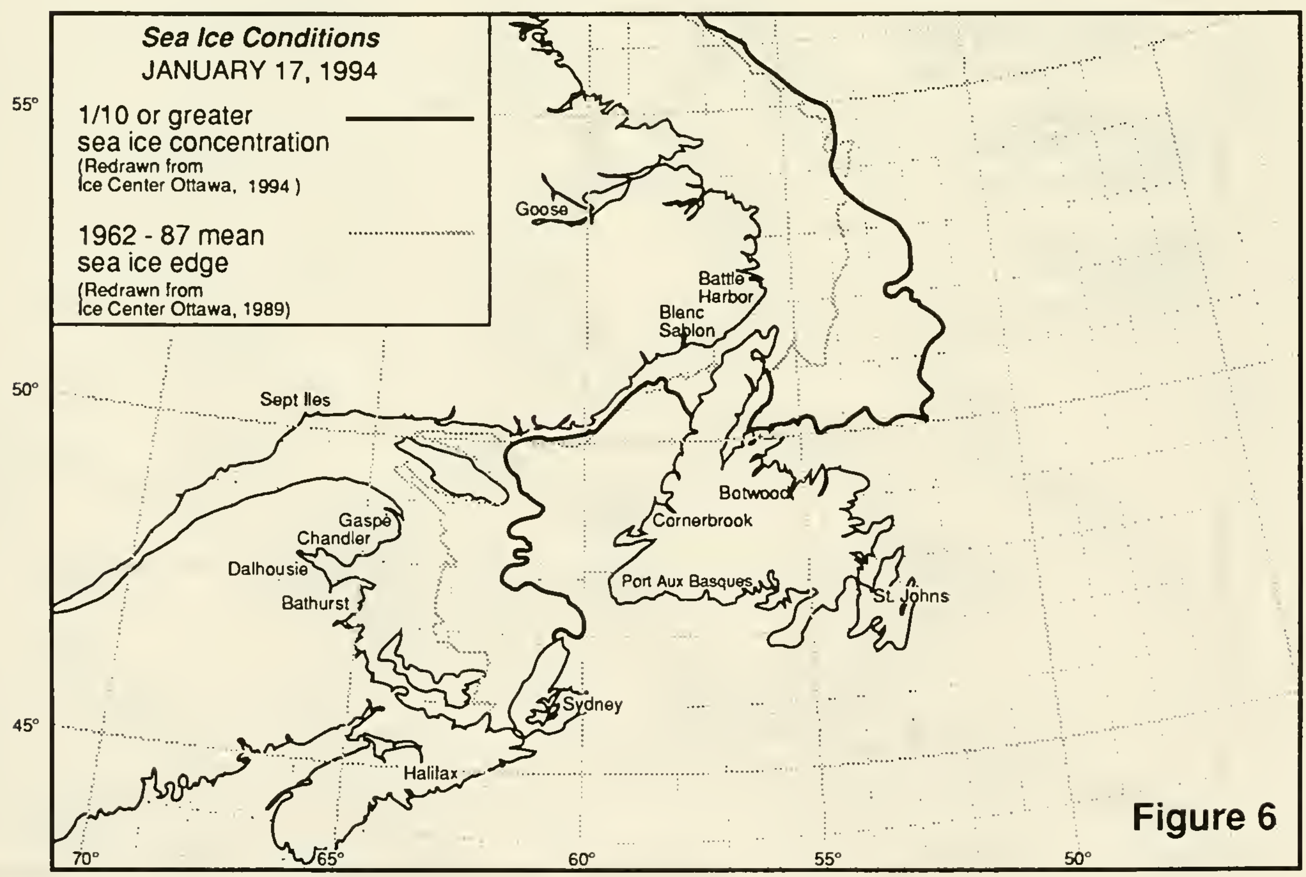


Figure 6

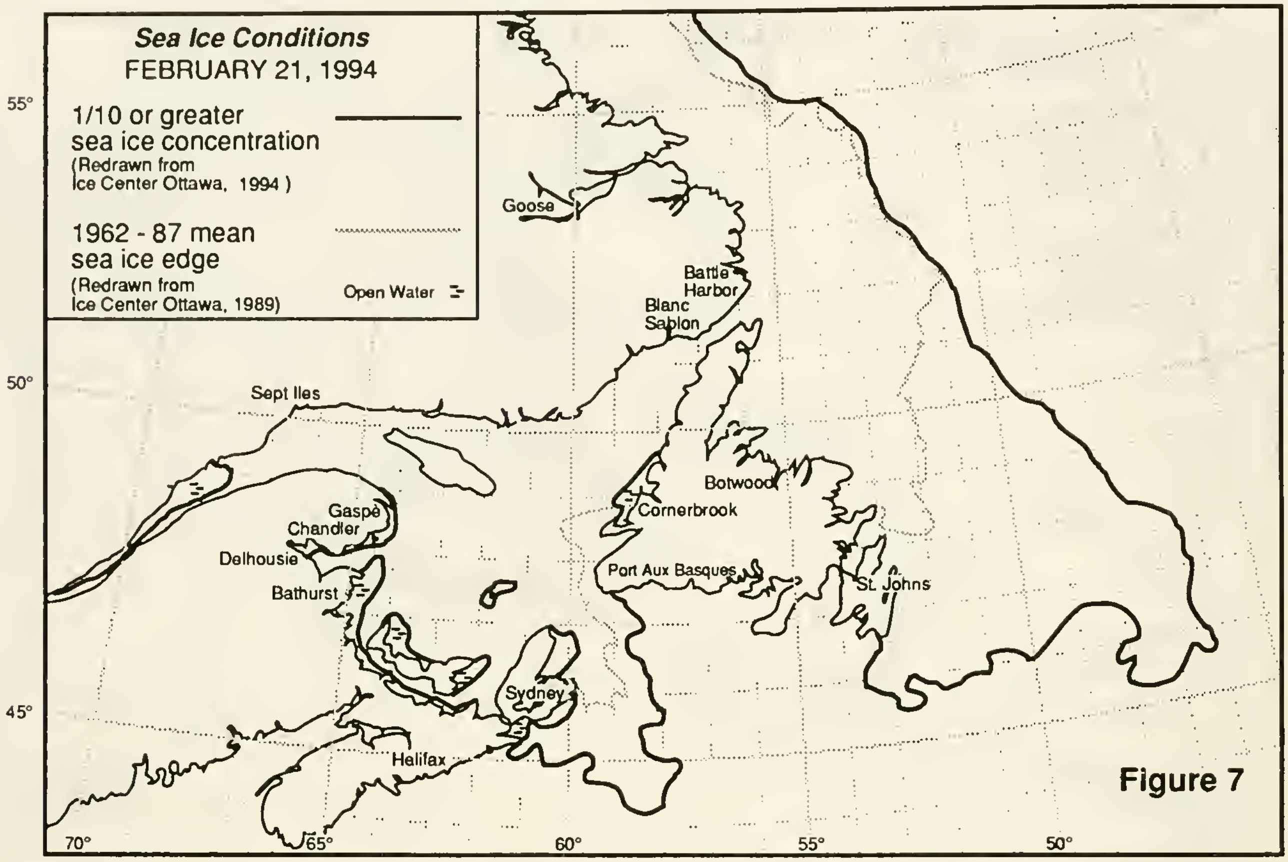


Figure 7

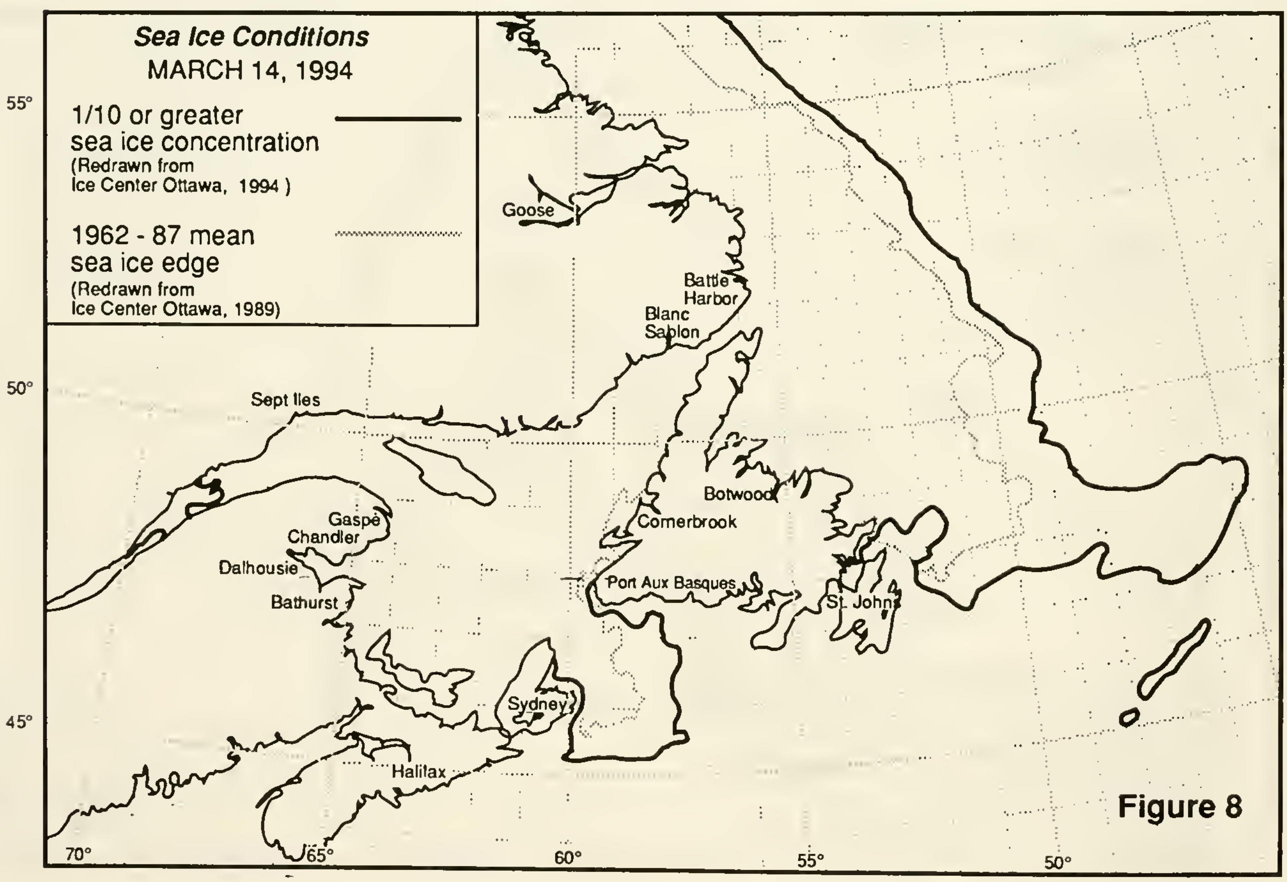


Figure 8

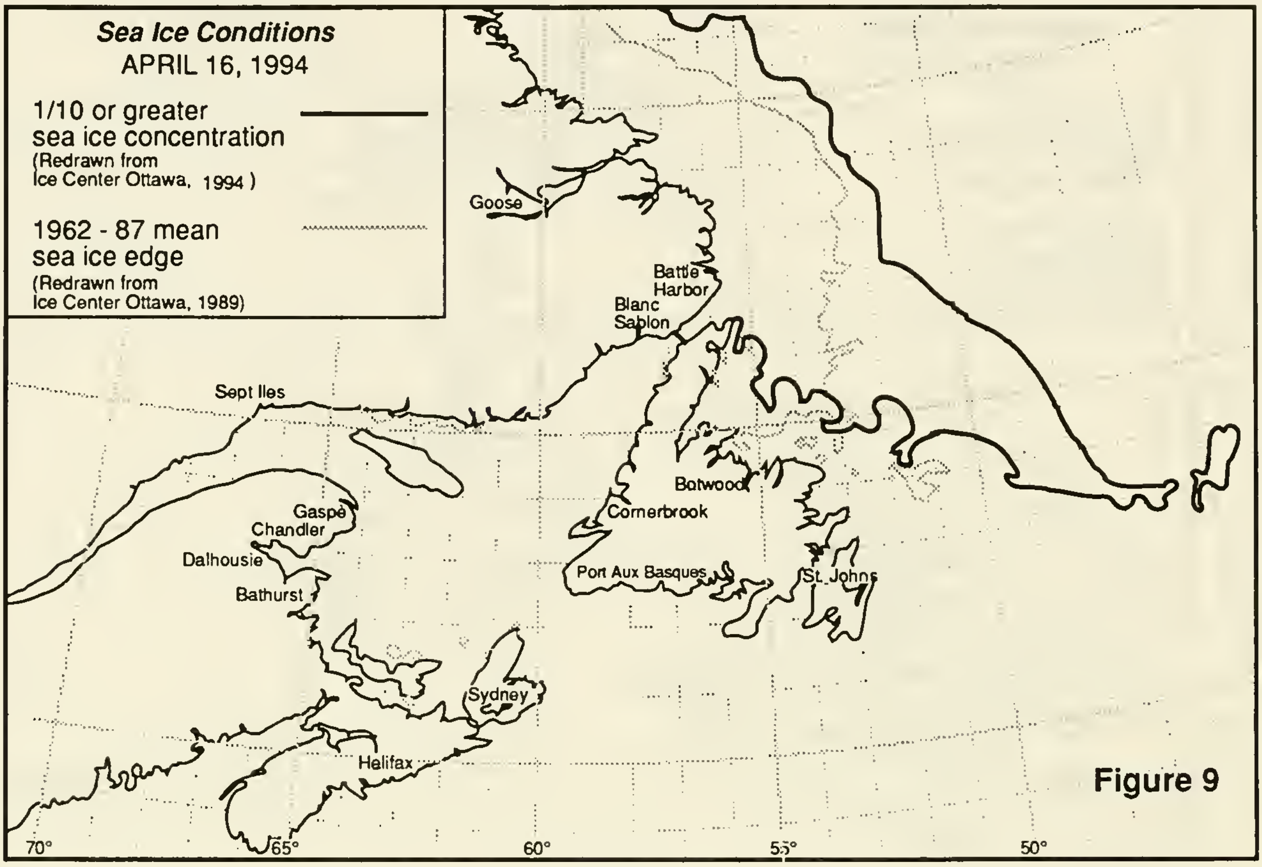


Figure 9

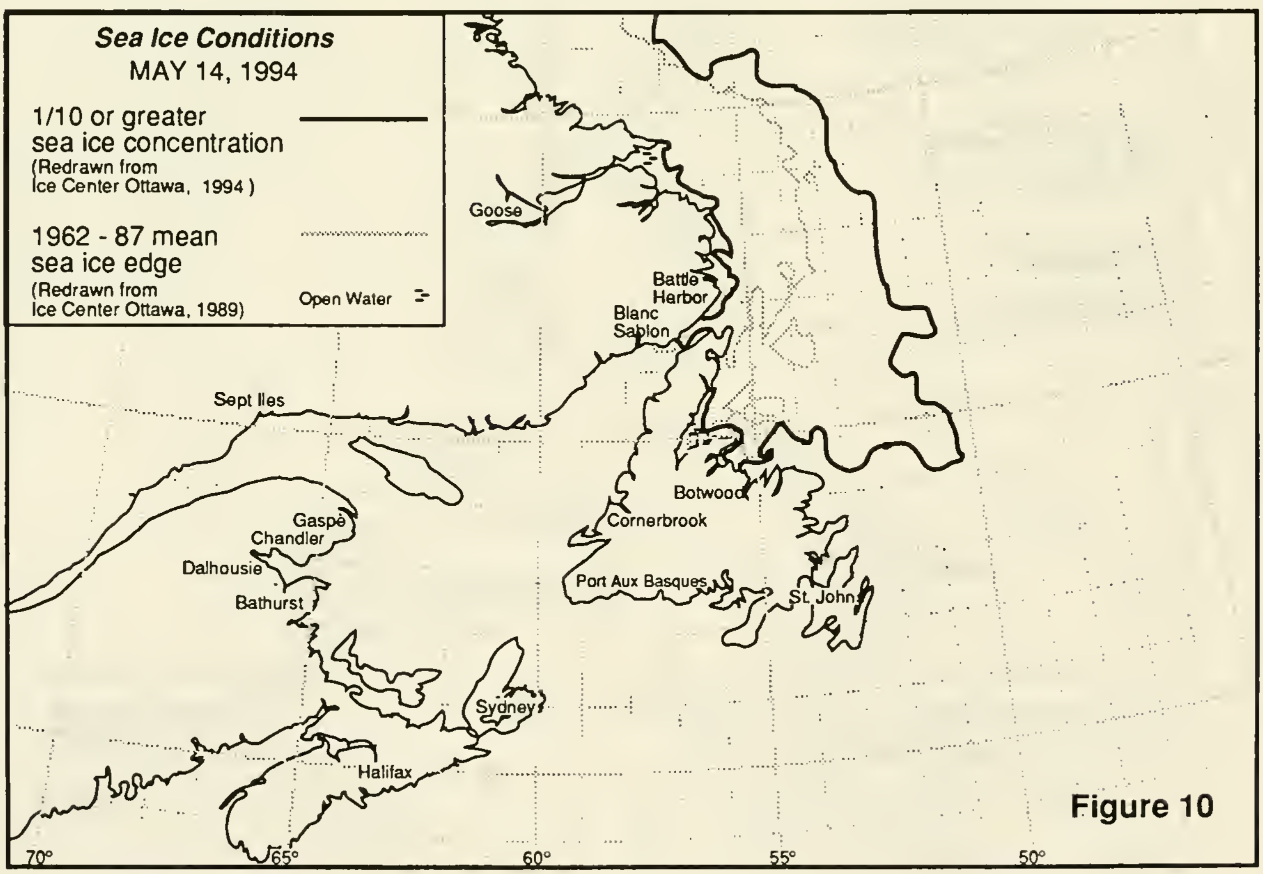


Figure 10

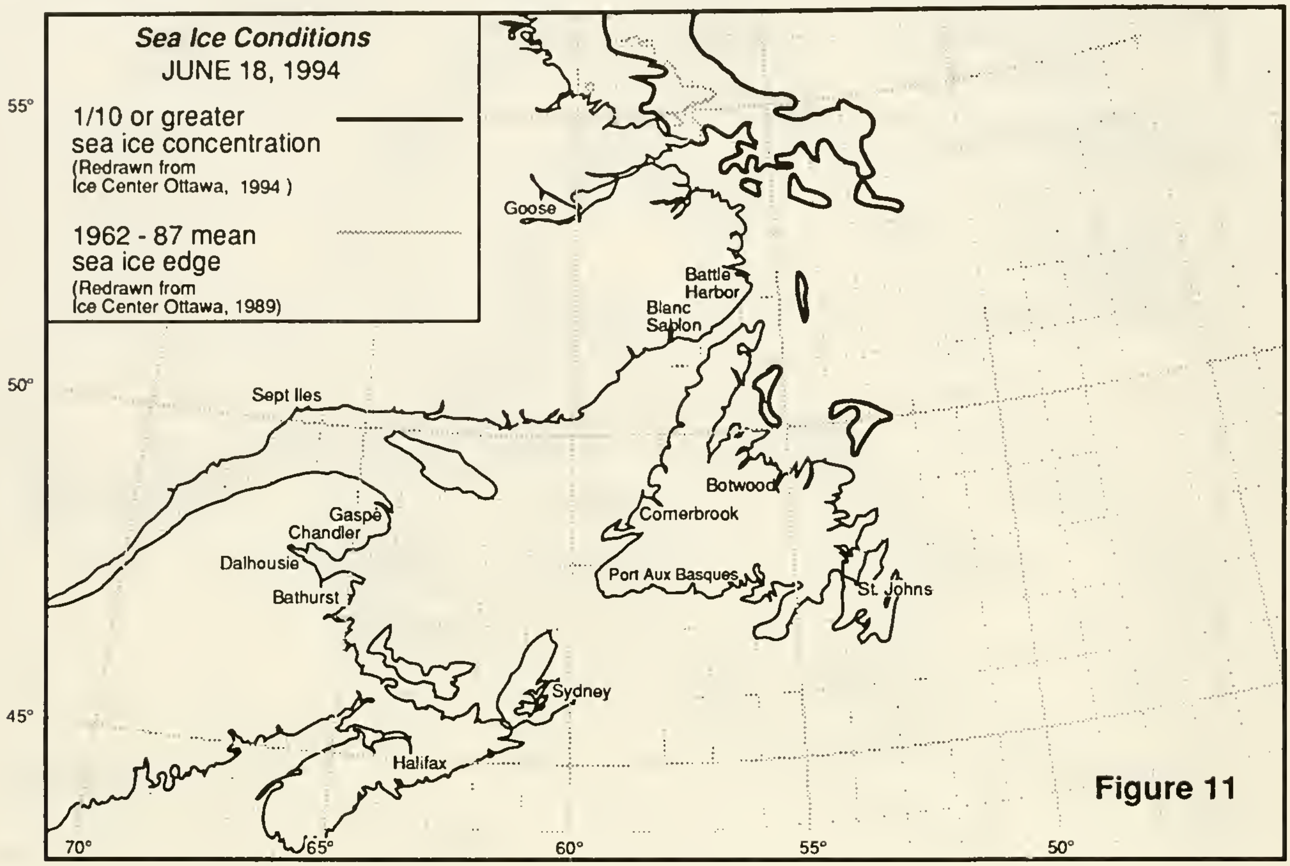


Figure 11

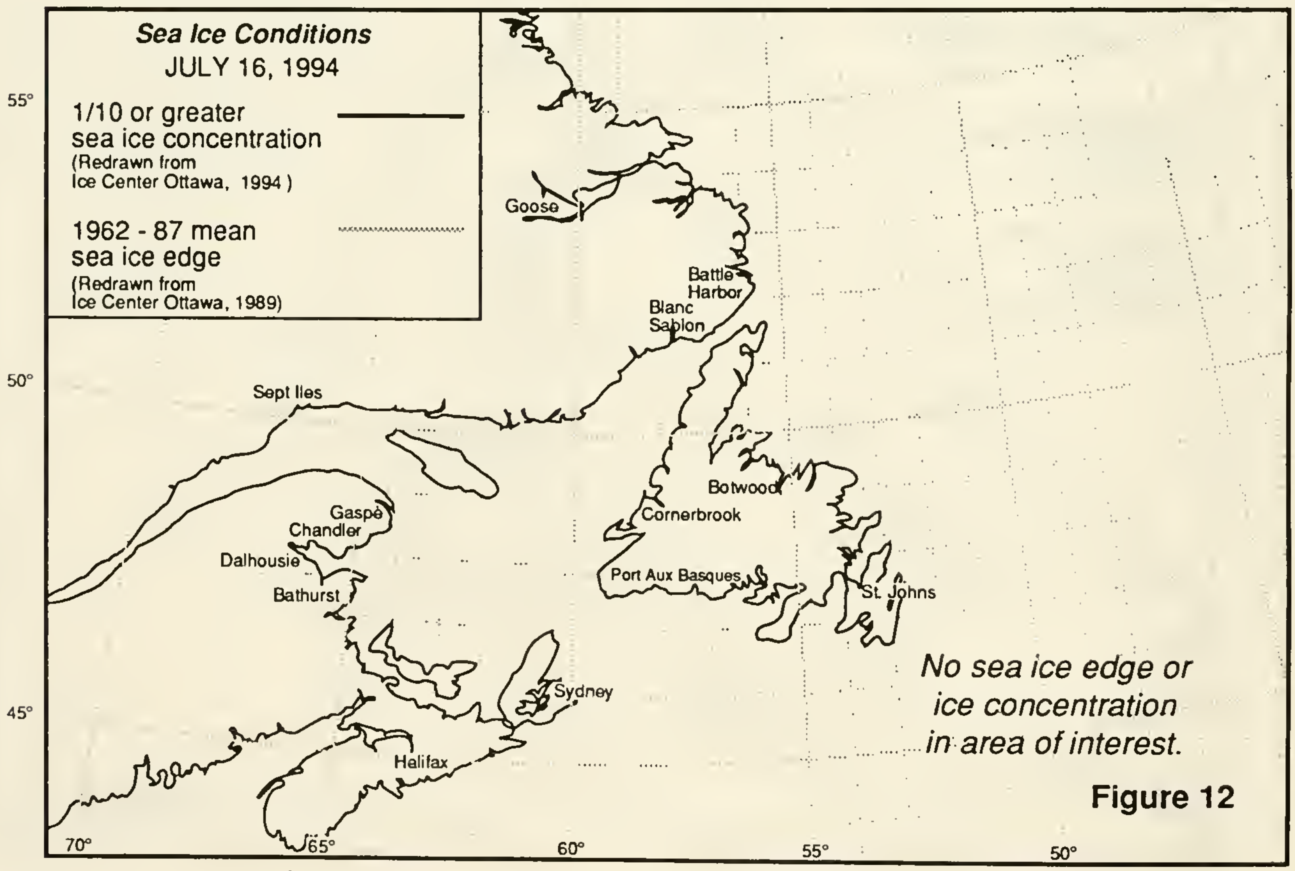


Figure 12

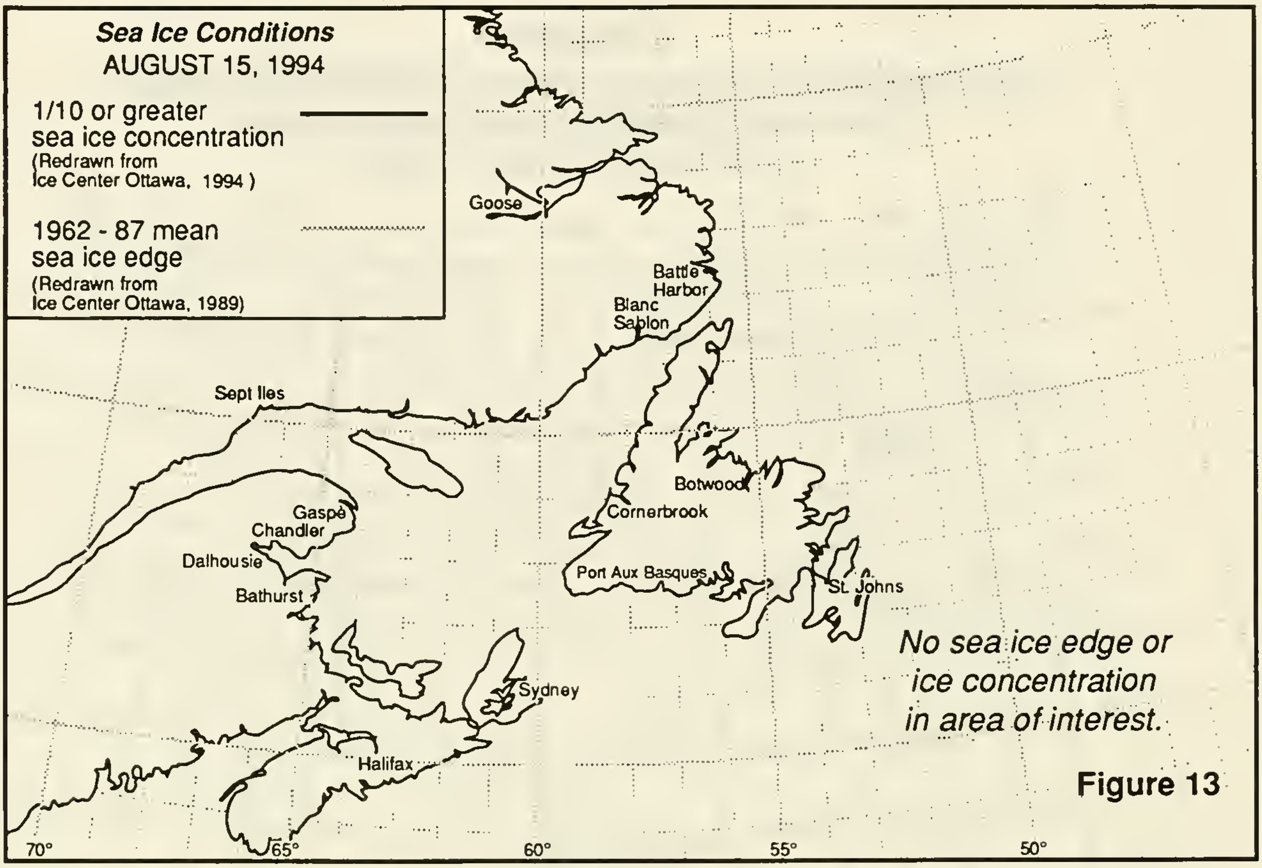


Figure 13

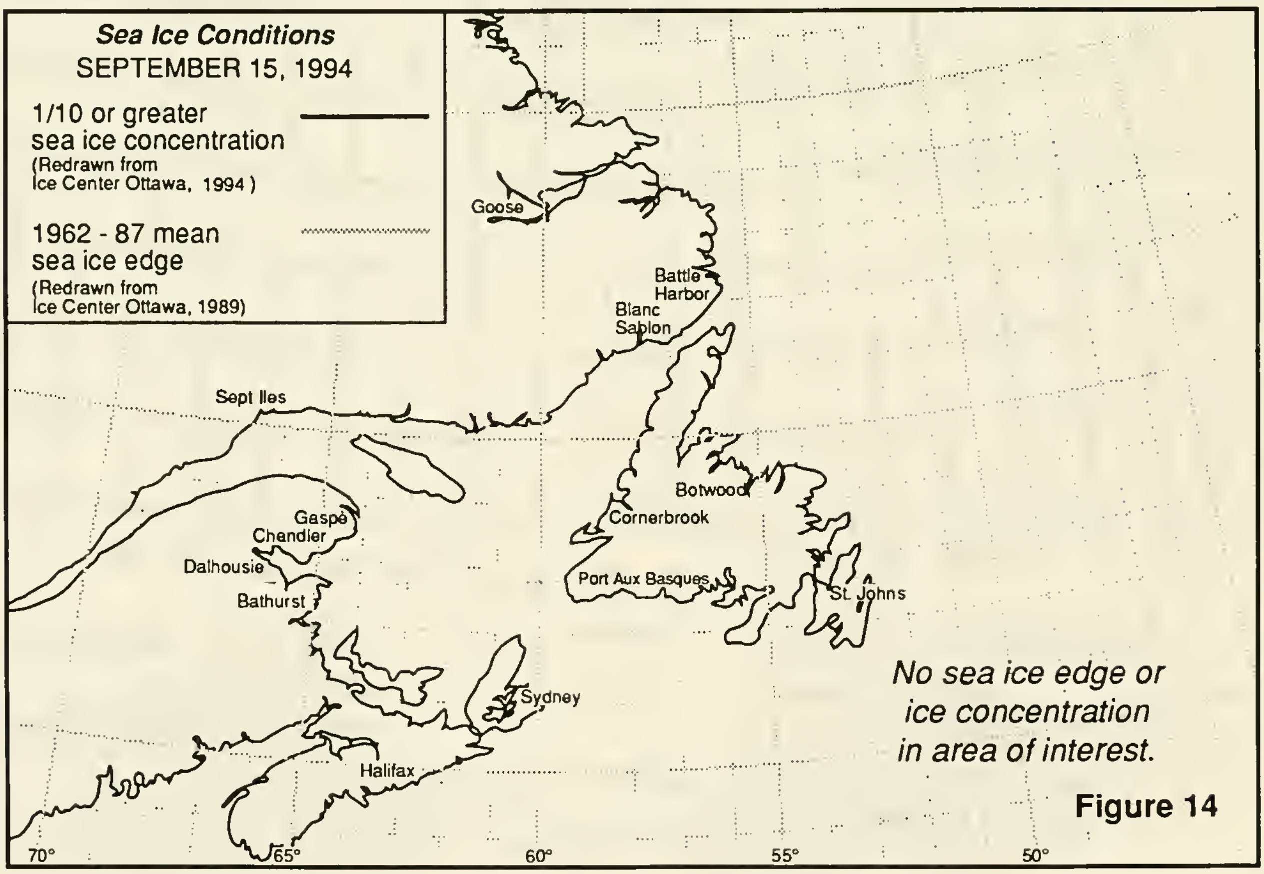


Figure 14

Figure 15

International Ice Patrol Ice Plot for **0000 GMT 23 Feb 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge

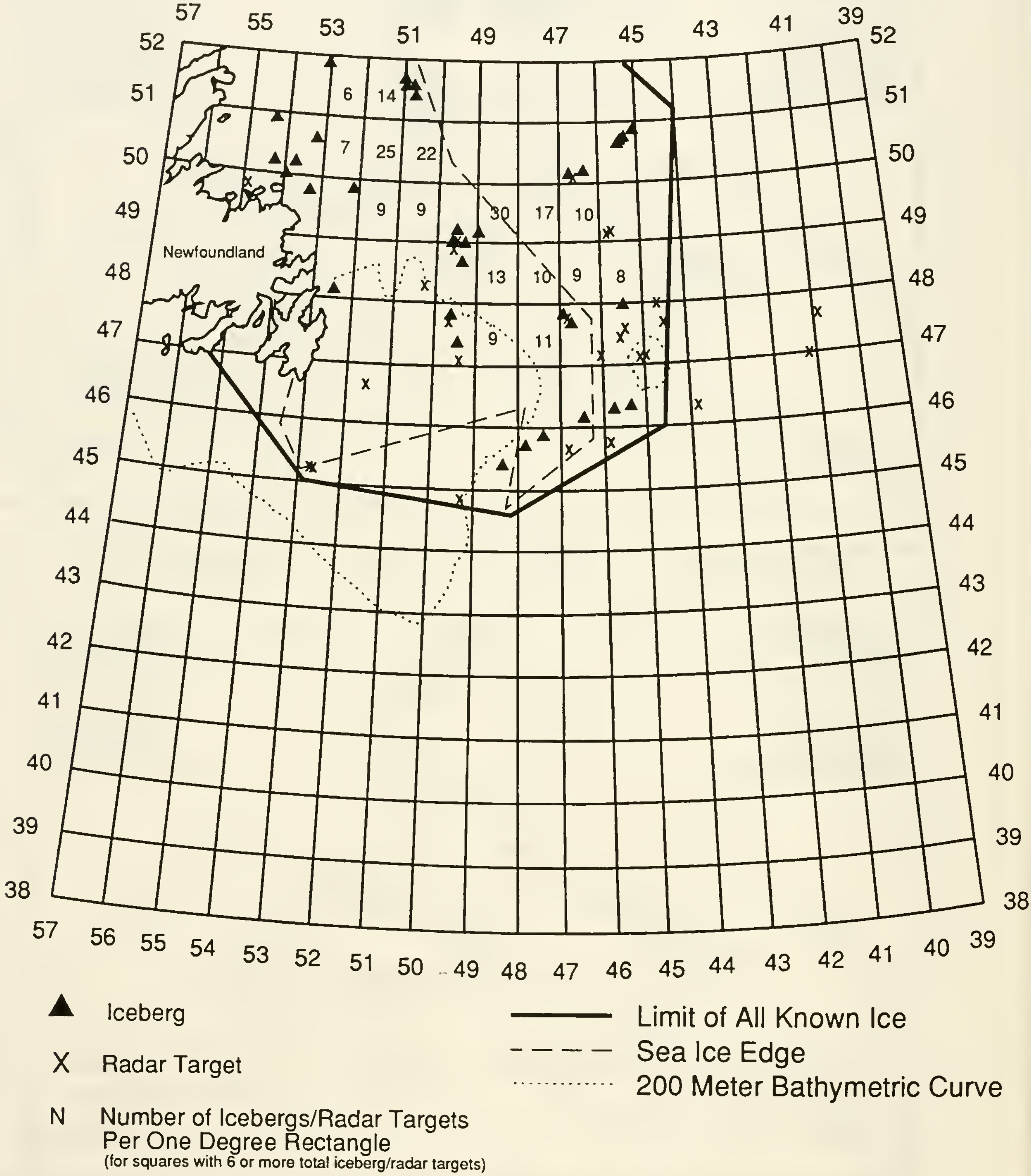


Figure 16

International Ice Patrol Ice Plot for **0000 GMT 28 Feb 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge

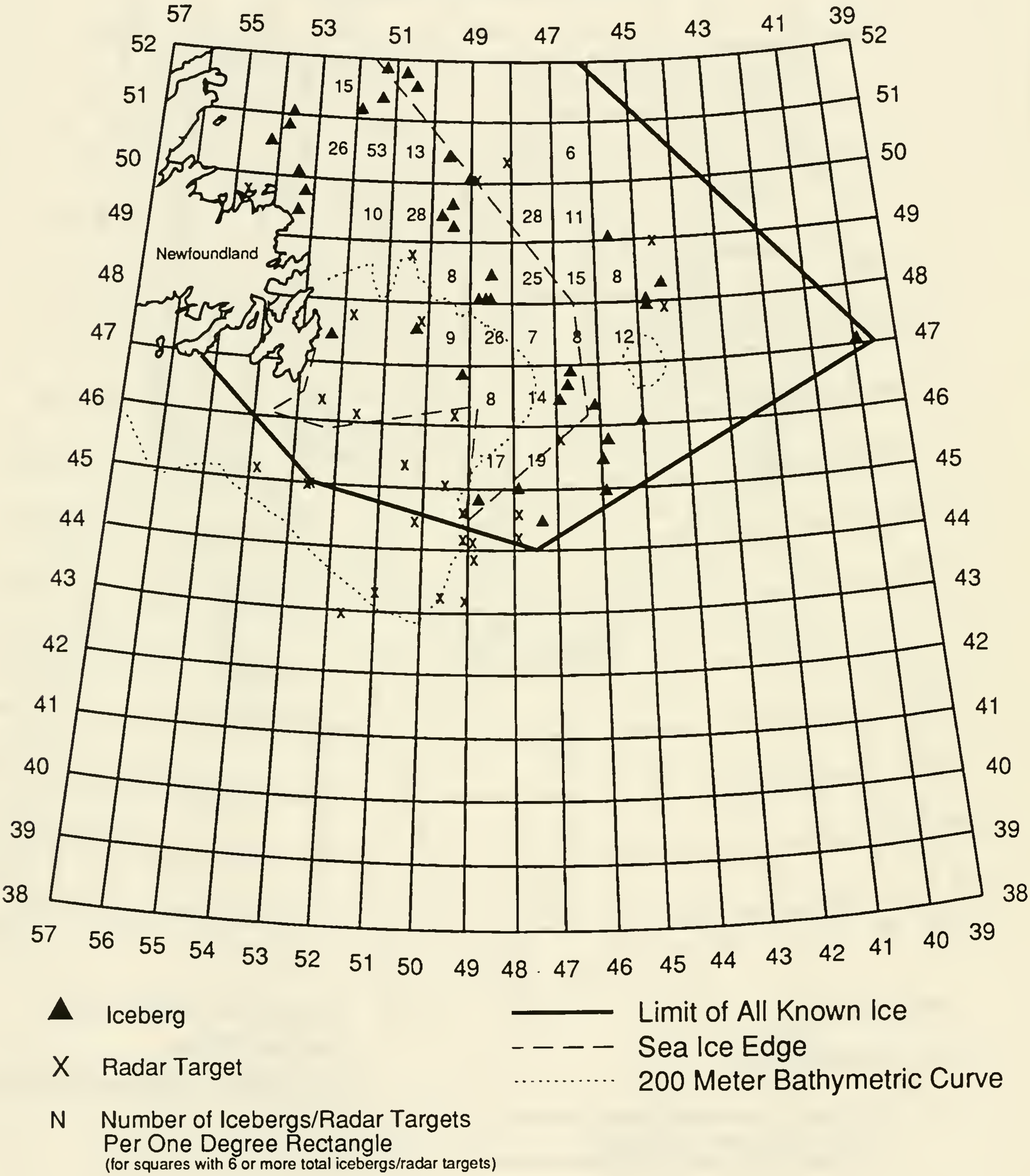
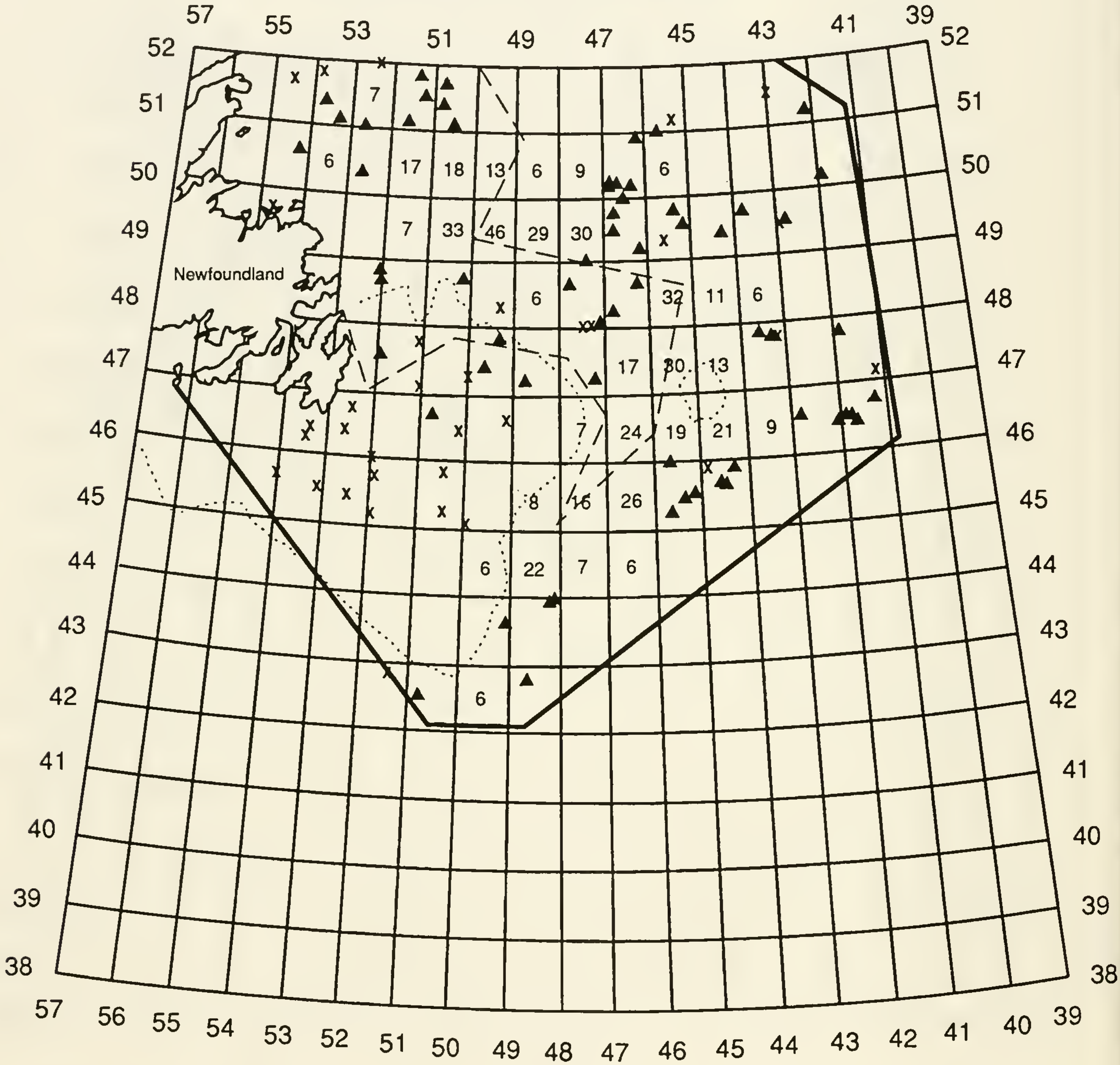


Figure 17

International Ice Patrol Ice Plot for **0000 GMT 14 Mar 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

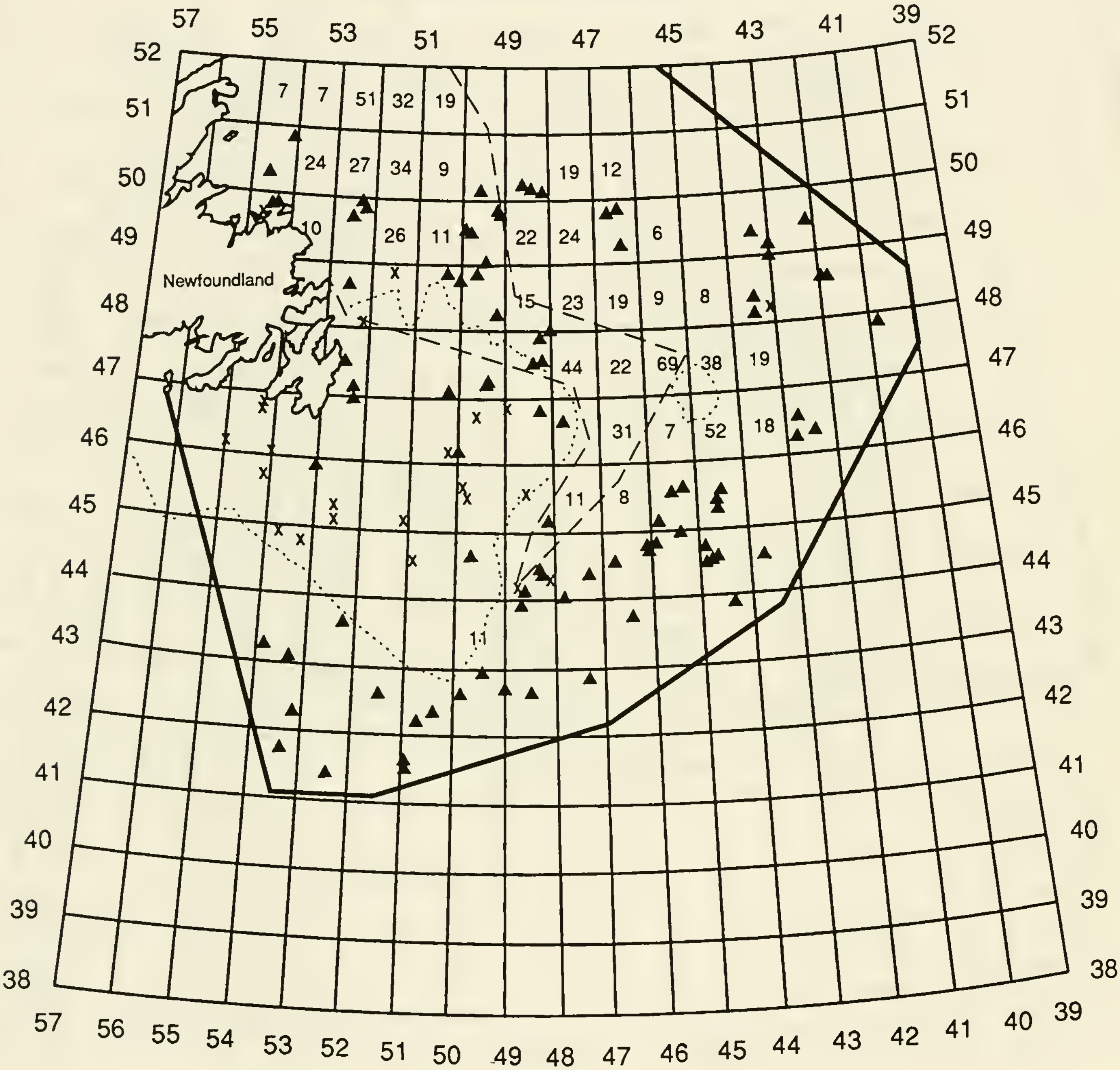
——— Limit of All Known Ice

– – – – Sea Ice Edge

·········· 200 Meter Bathymetric Curve

Figure 18

International Ice Patrol Ice Plot for **0000 GMT 31 Mar 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

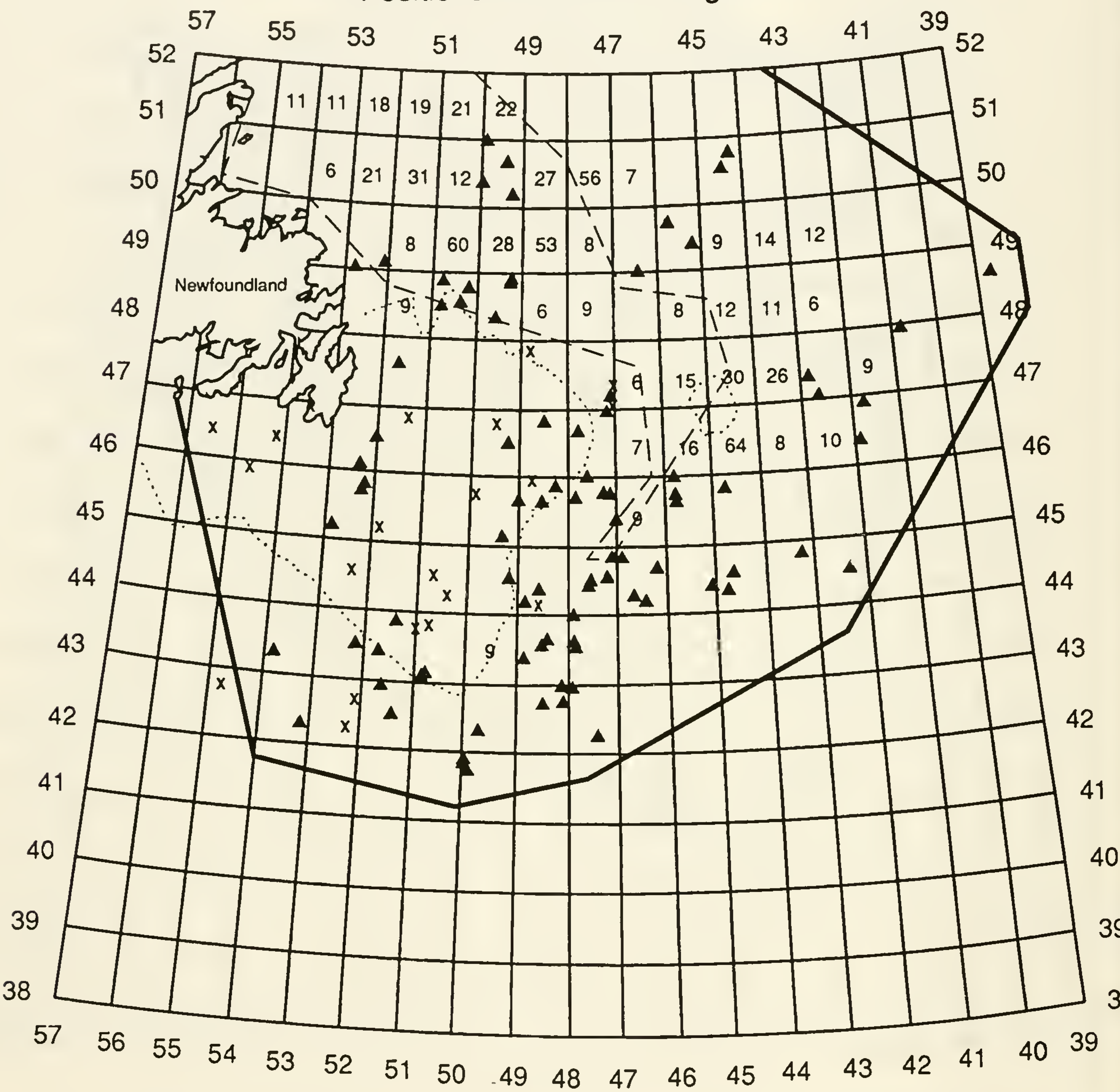
N Number of Icebergs/Radar Targets Per One Degree Rectangle (for squares with 6 or more total icebergs/radar targets)

——— Limit of All Known Ice

– – – – Sea Ice Edge

·········· 200 Meter Bathymetric Curve

Figure 19
International Ice Patrol Ice Plot for **0000 GMT 15 Apr 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets
Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

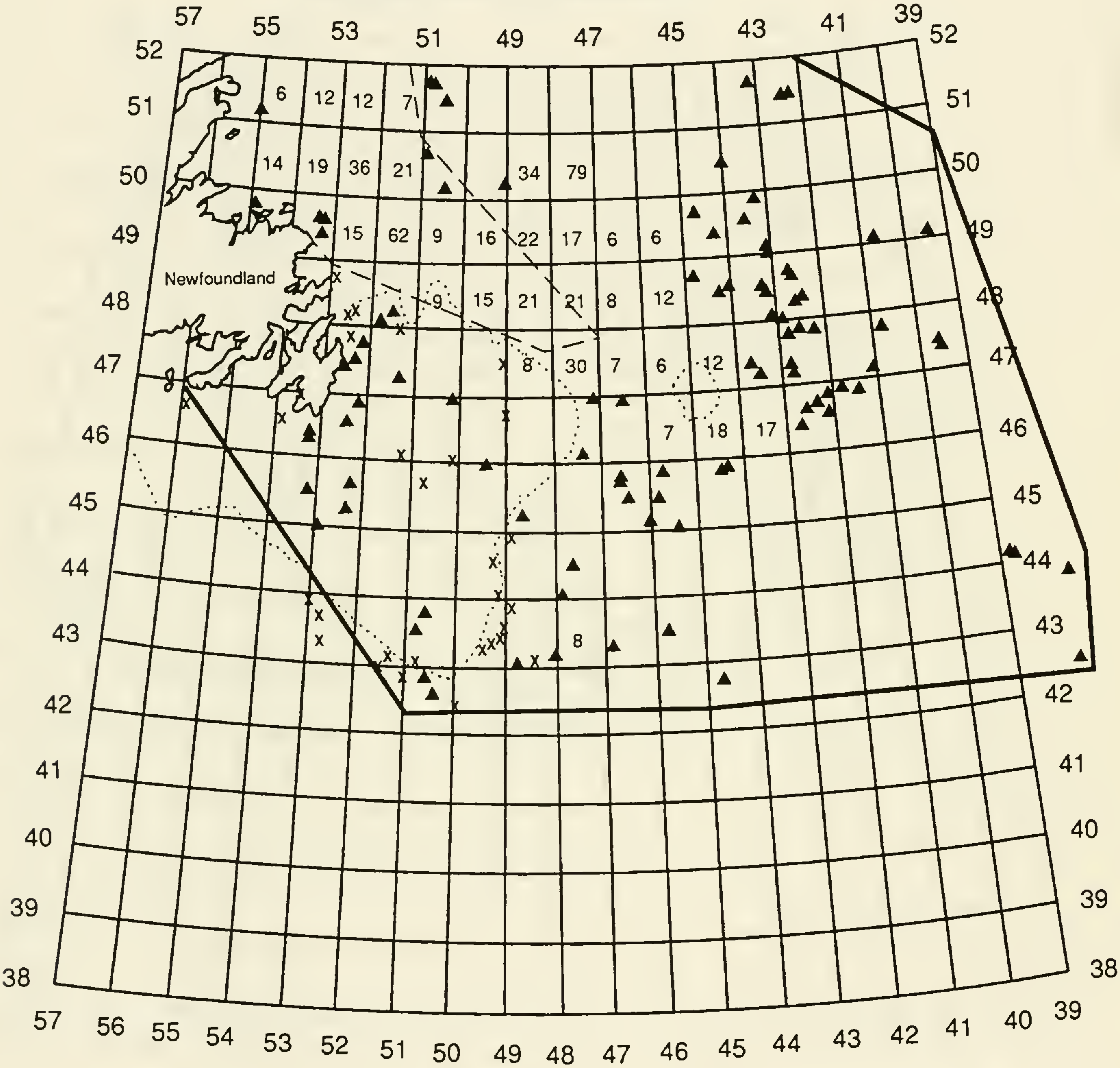
——— Limit of All Known Ice

– – – – Sea Ice Edge

············ 200 Meter Bathymetric Curve

Figure 20

International Ice Patrol Ice Plot for **0000 GMT 30 Apr 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

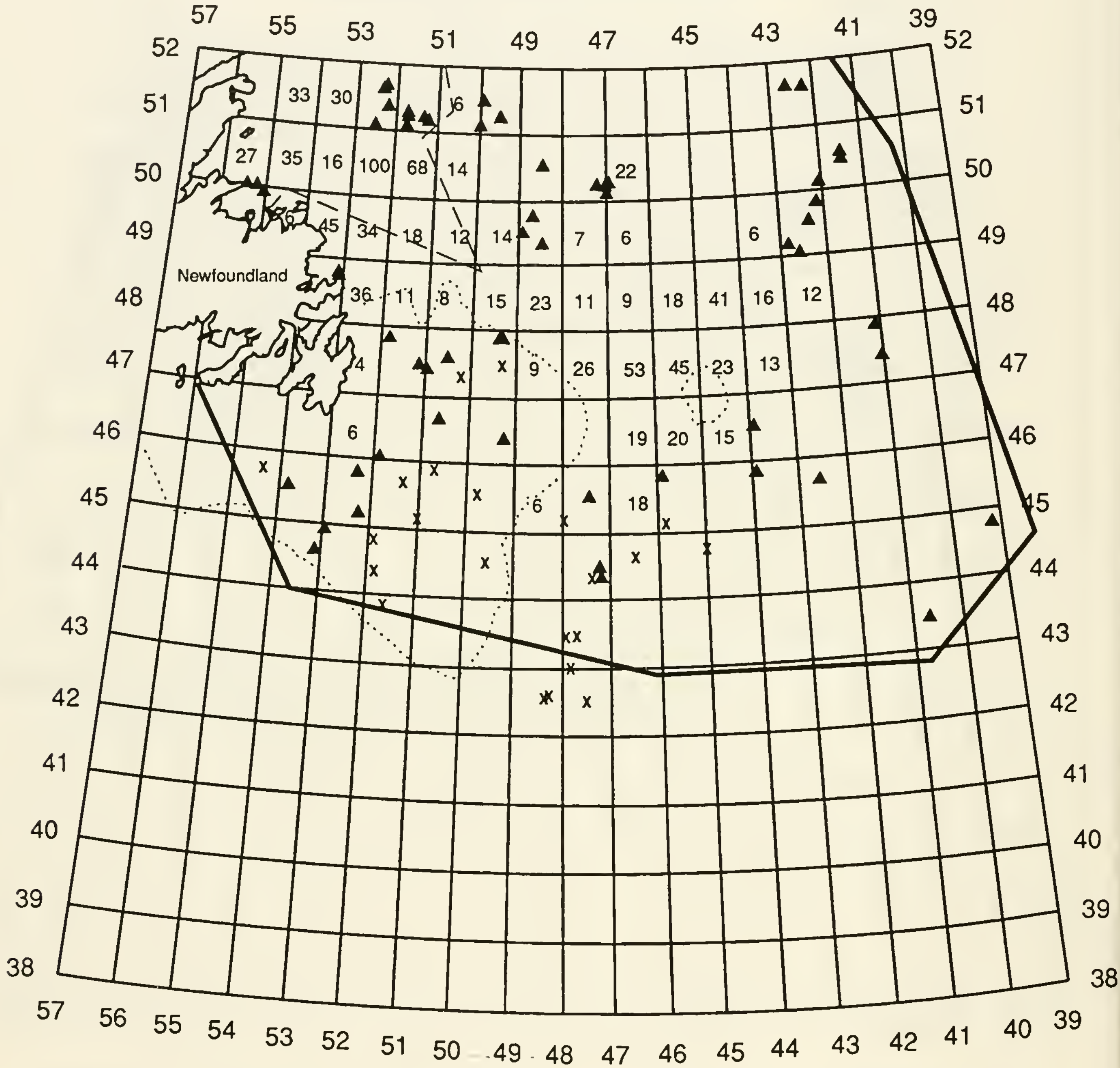
——— Limit of All Known Ice

– – – – Sea Ice Edge

··········· 200 Meter Bathymetric Curve

Figure 21

International Ice Patrol Ice Plot for **0000 GMT 15 May 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

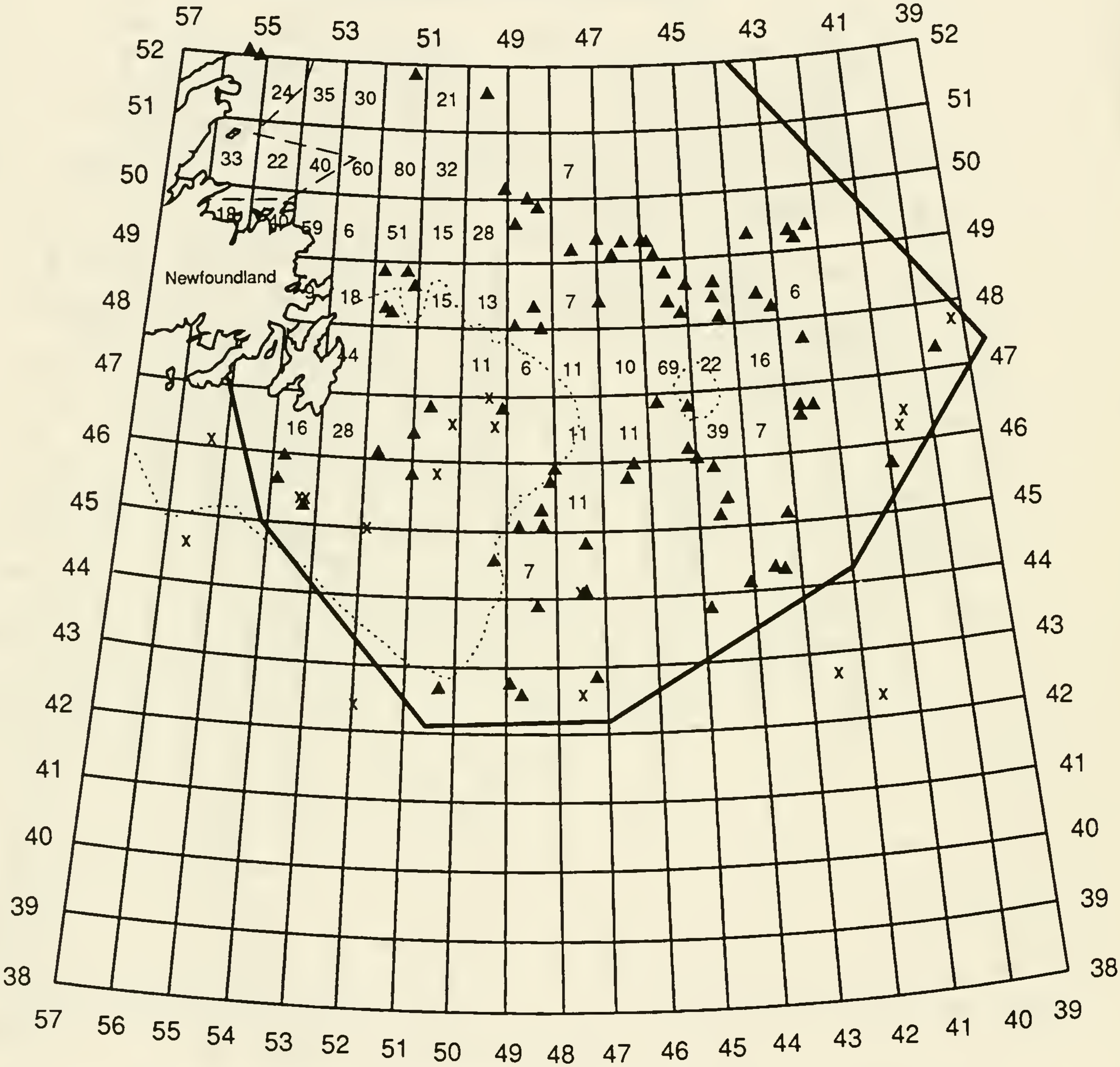
——— Limit of All Known Ice

– – – – Sea Ice Edge

·········· 200 Meter Bathymetric Curve

Figure 22

International Ice Patrol Ice Plot for **0000 GMT 30 May 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets
Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

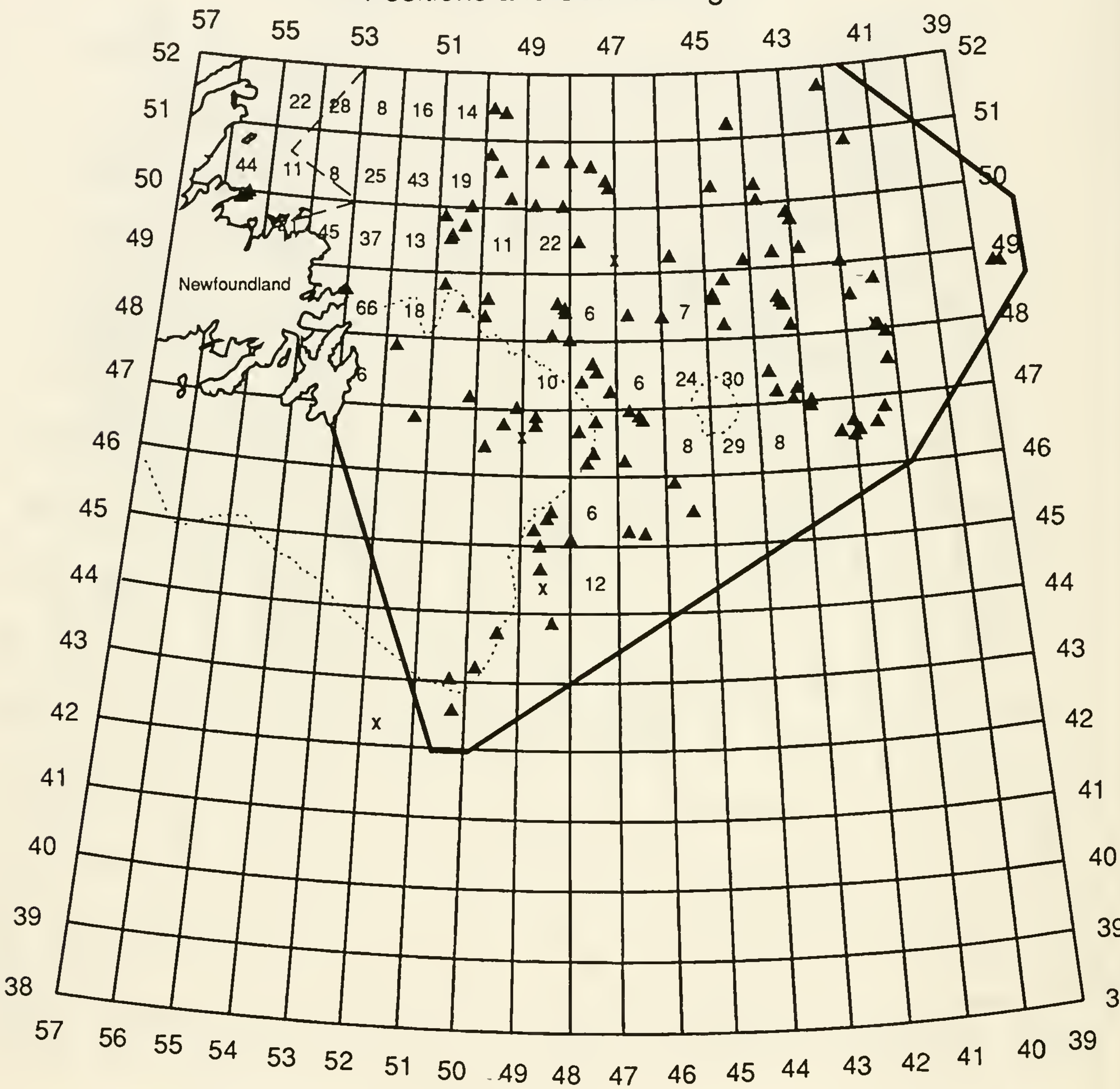
Limit of All Known Ice

Sea Ice Edge

200 Meter Bathymetric Curve

Figure 23

International Ice Patrol Ice Plot for **0000 GMT 14 Jun 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

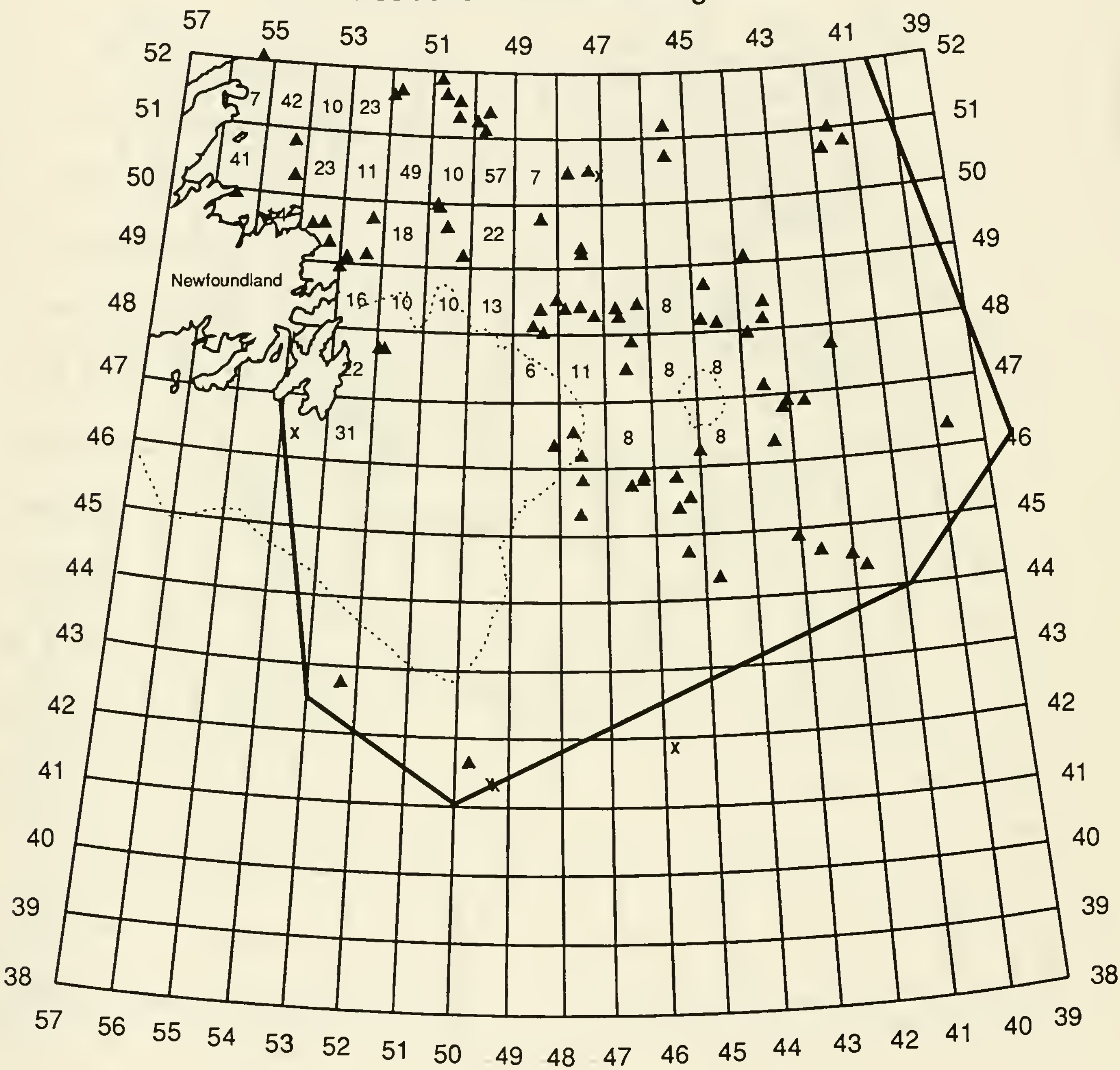
——— Limit of All Known Ice

- - - - Sea Ice Edge

.... 200 Meter Bathymetric Curve

Figure 24

International Ice Patrol Ice Plot for **0000 GMT 30 Jun 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets
Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

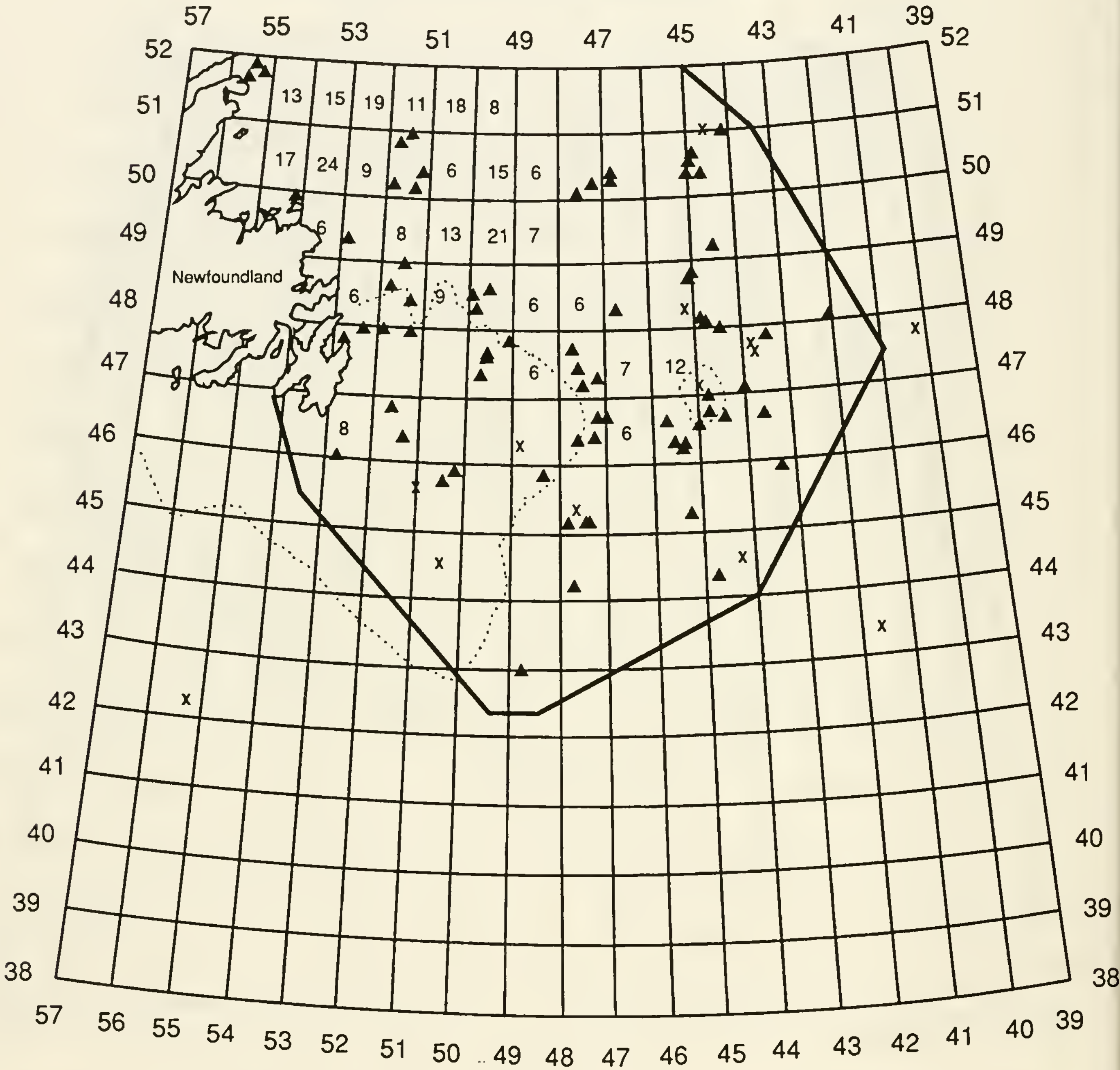
——— Limit of All Known Ice

– – – – Sea Ice Edge

·········· 200 Meter Bathymetric Curve

Figure 25

International Ice Patrol Ice Plot for **0000 GMT 15 Jul 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

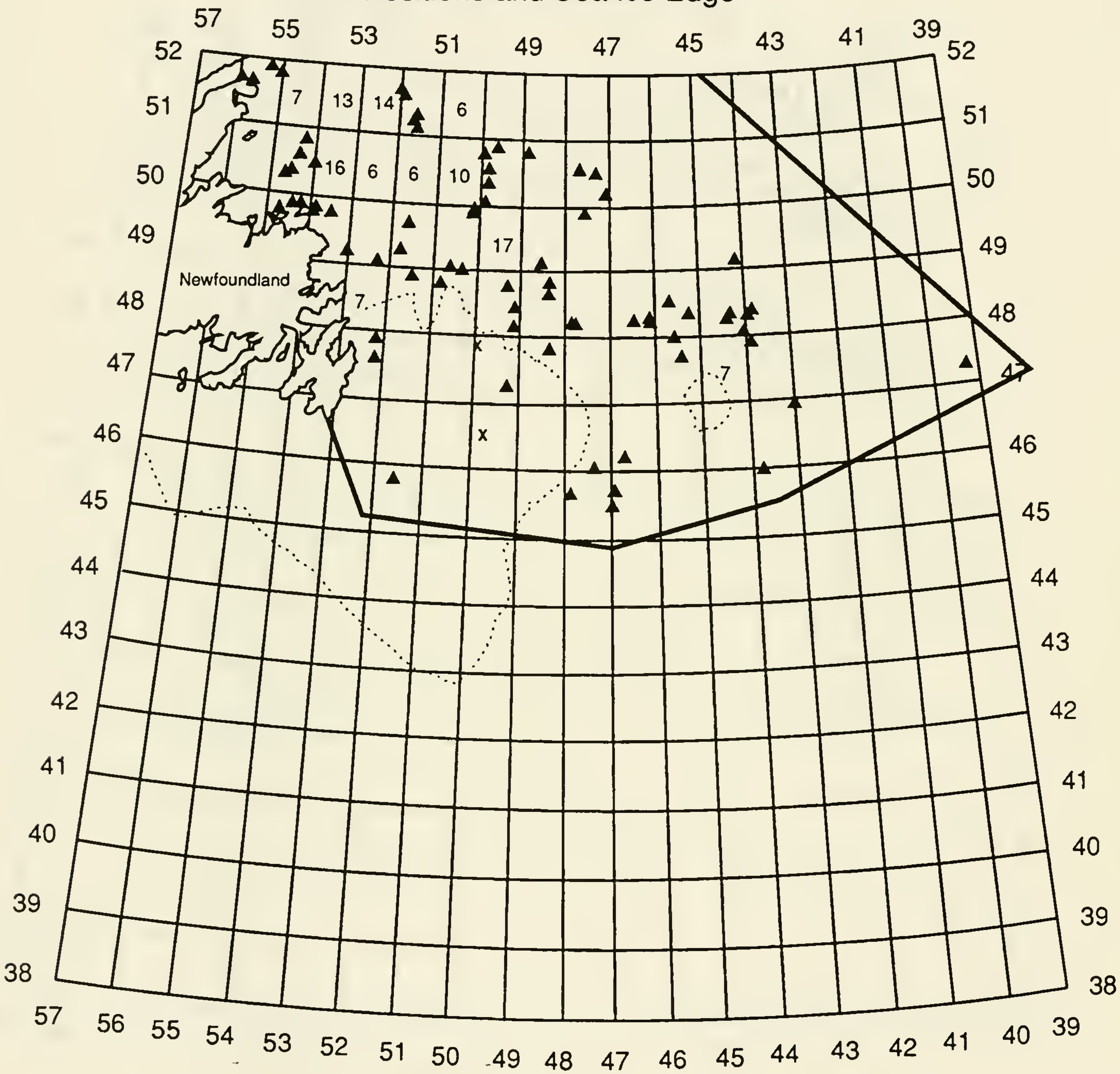
——— Limit of All Known Ice

– – – – Sea Ice Edge

············ 200 Meter Bathymetric Curve

Figure 26

International Ice Patrol Ice Plot for **0000 GMT 31 Jul 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets Per One Degree Rectangle (for squares with 6 or more total icebergs/radar targets)

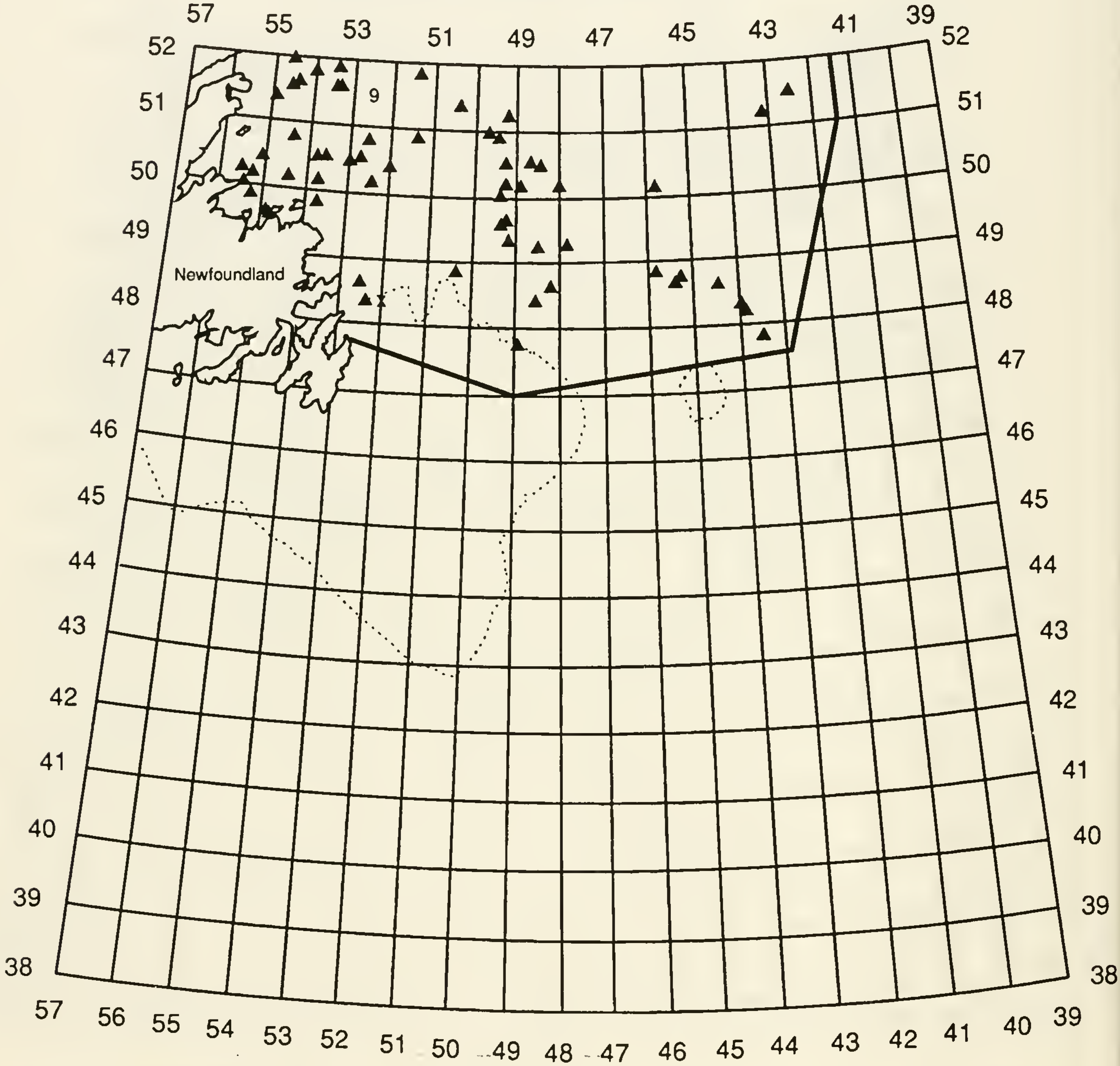
Limit of All Known Ice

Sea Ice Edge

200 Meter Bathymetric Curve

Figure 27

International Ice Patrol Ice Plot for **0000 GMT 14 Aug 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets Per One Degree Rectangle (for squares with 6 or more total icebergs/radar targets)

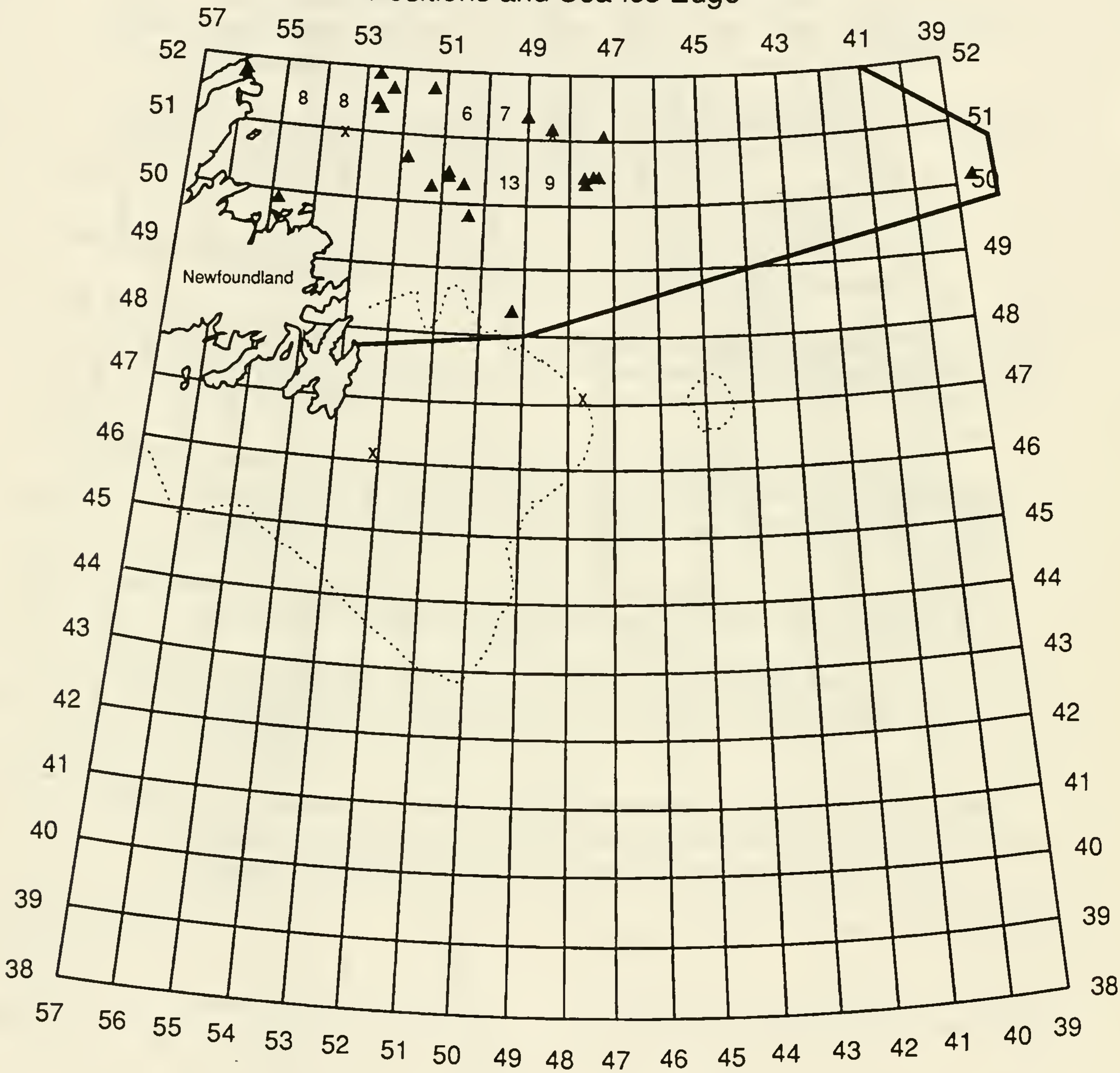
——— Limit of All Known Ice

– – – – Sea Ice Edge

··········· 200 Meter Bathymetric Curve

Figure 28

International Ice Patrol Ice Plot for **0000 GMT 30 Aug 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

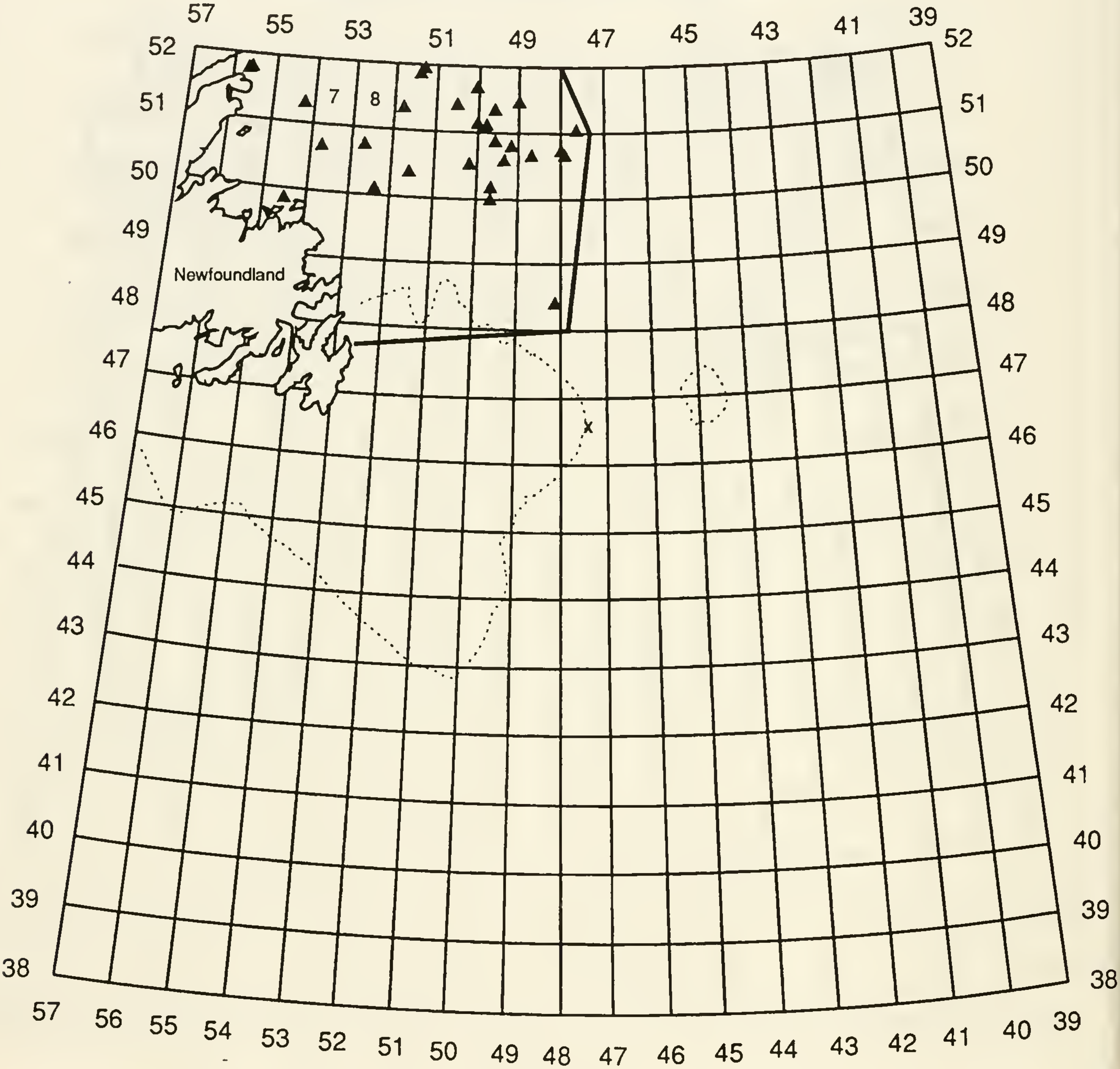
——— Limit of All Known Ice

– – – – Sea Ice Edge

·········· 200 Meter Bathymetric Curve

Figure 29

International Ice Patrol Ice Plot for **0000 GMT 02 Sep 94**
Showing Observed and Modeled Iceberg
Positions and Sea Ice Edge



▲ Iceberg

X Radar Target

N Number of Icebergs/Radar Targets Per One Degree Rectangle
(for squares with 6 or more total icebergs/radar targets)

—— Limit of All Known Ice

– – – – Sea Ice Edge

·········· 200 Meter Bathymetric Curve

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Coast Guard Atlantic Area Staff
First Coast Guard District Communications Center
First Coast Guard District Operations Center

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Ice Operation St John's, Newfoundland
Air Traffic Control Gander, Newfoundland
Canadian Forces Gander and St John's, Newfoundland
St. John's Weather Offices
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U.S. Coast Guard Air Station Cape Cod
U.S. Coast Guard Communications Station Boston
National Meteorological Center, Maryland

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It is also important to recognize the efforts of the personnel at the International Ice Patrol:

CAPT A. D. Summy
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LCDR B. E. Viekman
Dr. D. L. Murphy
Mr. G. F. Wright
LT G. A. Trivers
LT R. T. Haines
MSTCS D. R. Kennedy
MSTC J. F. Fisher
YN1 C. B. Peters
MST1 D. L. Alexander
MST1 V. L. Fogt
MST2 C. L. Channel
MST2 W. S. Barton
MST2 J. F. Cole
MST3 J. A. Jordan
MST3 J. T. Sobiesczyk
MST3 B. B. Keating

Appendix A

Nations Currently Supporting International Ice Patrol

BELGIUM	NORWAY
CANADA	PANAMA
DENMARK	POLAND
FINLAND	SPAIN
FRANCE	SWEDEN
GREECE	UNITED KINGDOM
ITALY	UNITED STATES
JAPAN	GERMANY
NETHERLANDS	

Appendix B
Ship Reports

Ship Name	Ship Flag	Ice Report	SST* Report
ABITIBI MACADO	LIBERIA	1	
ABITIBI ORINOCO	GERMANY	2	
ACADIENNCE GALE	CANADA	1	
ADA GORTHON	SWEDEN	11	
ADMIRAL ENGRACHT	NETHERLANDS	2	
A.G. FARQUHARSON	USA	1	
AIVIK	CANADA	4	
AIVIK	GERMANY	1	
AKADAN BULK	CYPRUS	1	
ALAM SEMPURNA	MALAYSIA	3	
ALEKSANDER ABERG	RUSSIA	1	
ALEXANDRIA	SUDAN	2	
AMICA	NORWAY	1	
ANAX	PANAMA	1	
ARIETTA	RUSSIA	1	
ARGIRONISSOS	GREECE	2	
ARCTIC	CANADA	5	
ARABIAN SEA	PANAMA	2	
ARROW NIKI	NORWAY	2	
ARGOSY	INDIA	1	
ARKONA	GERMANY	1	
ASPIS	CYPRUS	1	
ATLANTIC BREEZE	JAPAN	1	
ATLANTIC CARTIER	BAHAMAS	2	
ATLANTIC COMPASS	SWEDEN	1	
ATLANTIC CONVEYER	UNITED KINGDOM	3	
ATLANTIC FORREST	CANADA	1	
BARTOLOMEU DIAS	PORTUGAL	5	
BALTIJAS PETNIEKS	RUSSIA	1	
BAKENGRACHT	NETHERLANDS	1	
BARONIA	UNKNOWN	2	
BELLE	MALTA	1	
B M HASS	BAHAMAS	1	
BERGE LORD	NORWAY	1	
BERGE MASTER	NORWAY	2	
BERGEN SEA	NORWAY	4	2
BERGEN SPLENDER	NORWAY	1	
BRIGHT SEA	CYPRUS	1	
BONN EXPRESS	GERMANY	1	
BOW STAR	NORWAY	6	
BYNNOVE KNUTSEN	UNKNOWN	1	

* Sea Surface Temperature

Ship Name	Ship Flag	Ice Report	SST* Report
CAMILLA	FINLAND	12	
CANMAR AMBASSADOR	BERMUDA	10	
CANMAR CONQUEST	UNITED KINGDOM	3	
CANMAR TRIUMPH	UNITED KINGDOM	33	
CANMAR VENTURE	CANADA	5	
CANMAR VALIANT	CROATIA	12	4
CANMAR VICTORY	UNITED KINGDOM	8	
CANADIAN LIBERTY	LIBERIA	2	
CAPE CATHAY	TAIWAN	1	
CAPE EUROPE	TAIWAN	2	2
CAPE HATTERAS	LIBERIA	2	
CARBUNESTI	LIBERIA	1	
CAST BEAVER	CROTIA	13	
CAST HUSKY	BAHAMAS	7	5
CAST MUSKOX	BAHAMAS	56	56
CAST OTTER	BAHAMAS	12	
CAST POLAR BEAR	CROATIA	65	50
CATHERINE DESGAGNE	UNKNOWN	1	
CHAD	UNKNOWN	2	
CHIMO	NORWAY	2	
CHELYABINSK	UKRAINE	2	
CHOWTAW	UNITED KINGDOM	1	
COLUMBIA LAND	SINGAPORE	1	
COMPANION EXPRESS	SWEDEN	1	
CONCORD	GERMANY	5	1
CONSTANCE	UNKNOWN	1	
CROSBY	BAHAMAS	1	
CRYSTAL GRACE	PHILIPPINES	1	
CVIJETA ZUZORIC	SAN MARINO	2	
DAGEID	BAHAMAS	1	
DAGHILD	NORWAY	1	
USCGC DALLAS	USA	2	2
DARFUR	CYPRUS	1	
DARYA SHUBH	LIBERIA	2	2
DES GROSEILLIERS	CANADA	4	
DETTIFOSS	CYPRUS	5	
DIAMOND	NORWAY	1	
DIAMOND STAR	CANADA	2	
DIAVOLEZZA	SWITZERLAND	9	
DOBRUSH	UKRAINE	2	
DSR-AISA	GERMANY	1	
DURRINGTON	UNITED KINGDOM	1	
EASTERN BRIDGE	BAHAMAS	1	
ELISABETH BOYE	DENMARK	1	
EMERALD RIVER	JAPAN	1	1

* Sea Surface Temperature

Ship Name	Ship Flag	Ice Report	SST* Report
EPTANISSA	CUBA	1	
EPOS	UNKNOWN	3	
ETHNIC	GREECE	3	
EUROPE FEEDER	UNKNOWN	5	
FAME	CANADA	1	
FARQUHARSON	CANADA	10	
FEDERAL	USA	2	
FEDERAL AGNO	PHILIPPINES	2	
FEDERAL DANUBE	CANADA	25	7
FEDERAL FRASER	PHILIPPINES	2	
FEDERAL MANITOU	NORWAY	1	
FEDERAL MAAS	CANADA	18	
FEDERAL OTTAWA	LUXEMBORG	4	
FEDERAL OSLO	NORWAY	1	
FEDERAL SAGUENAY	CANADA	2	
FEDERAL SCHELDE	LIBERIA	2	
FEDERAL THAMES	CANADA	5	
FEDERAL POLARIS	LIBERIA	1	
FETISH	DENMARK	4	
FIDELIO	USA	1	1
FINN FIGHTER	BAHAMAS	15	
FREJA SVEA	DENMARK	1	
FRINES	LIBERIA	1	
GALVESTON BAY	USA	1	
HMCS GATINREU	CANADA	4	
GEORGE	GREECE	1	
GEORGE R PEARKS	CANADA	5	4
GOOD FAITH	LIBERIA	8	7
GOLDEN HOPE 8	PANAMA	1	
GORTHON	SWEDEN	1	
GREEN FRIO	UNKNOWN	2	
GUS W DARNELL	USA	5	
HALGA FELLI	DENMARK	1	
HELENA HUDIG	LUXEMBORG	1	
HELENA OLDENORFF	GERMANY	14	
HENRY LARSON	CANADA	3	
HERALD	BRITISH	2	1
HERCEGOVINA	MALTA	4	3
HOFSJOKULL	ICELAND	4	
HORTON	UNKNOWN	1	
HUDSON	CANADA	3	
HUBERT GAUCHER	CANADA	2	
HUMBOLT EXPRESS	GERMANY	1	
HUSNES	PANAMA	1	
ICE PEARL	DENMARK	1	

* Sea Surface Temperature

Ship Name	Ship Flag	Ice Report	SST* Report
IJMUIDEN MARU	PANAMA	1	
IMANT SUDMAL	RUSSIA	2	
IOLOCOS SPIRT	CYPRUS	1	
IRAFOSS	UNKNOWN	1	
IRAN SAEIDI	IRAN	1	
IRVING ESKIMO	CANADA	1	
IVAN BOGOUM	UKRAINE	1	
IVAN GORTHON	SWEDEN	3	
J E BERNIER	CANADA	3	
JEROM	LIBERIA	4	
JOHANNA KRISTINA	DENMARK	1	
JOHN GORTHON	SWEDEN	10	
JOLLITY	UNKNOWN	1	
JULIA	FINLAND	2	
JURIS AVOTS	LATVIA	5	
KAPITONAS A LUCKA	RUSSIA	2	
KAPITONAS GUDIN	RUSSIA	4	
KAPITONAS STULPINAS	RUSSIA	8	
KAPITONAS TZMIAKOV	LITHUANIA	2	
KAPITONAS VAVLIOV	RUSSIA	2	
KAPITAN TKACHENKO	LIBERIA	1	
KAPITON ZHURAVLYOY	RUSSIA	1	
KAMARI	CYPRUS	1	
KENT ATLANTIC	NORWAY	1	
KIHU	FINLAND	1	
KOOPERATSIYA	LIBERIA	1	
KNOKN NALLING	LIBERIA	1	
KQDOVILJA	AFGHANISTAN	1	
LADY FRANKLIN	CANADA	2	
LAKE CARLING	USA	37	5
LAKE CHAMPAIN	PANAMA	1	
LARINA	NORWAY	13	
LCG LARSON	UNKNOWN	1	
LE CHENE 1	CANADA	9	
LE SAULE 1	CANADA	3	
LEONARD J COWLEY	CANADA	4	
LIA	LIBERIA	1	
LIBERTY SKY	PANAMA	2	
LILY	BRAZIL	10	
LINDA MAXINE	CANADA	5	
LIPNO	CZECH REPUBLIC	1	1
LOTILA	FINLAND	1	
LUCIEN PAQUIN	CANADA	3	
MALIK 2	NEW HEBRIDES	5	
MAMRY	POLAND	6	4

* Sea Surface Temperature

Ship Name	Ship Flag	Ice Report	SST* Report
MARIA GORTHON	SWEDEN	3	
MATHILDE MAERSK	DENMARK	1	
MATTEW	CANADA	1	
MATHILDA DESGAGNES	CANADA	1	
MARINE STAR	MONACO	1	
MARINOS	CYPRUS	1	
MARJA	NETHERLANDS	2	
MARSHAL KONEV	RUSSIA	2	
MAYA	GERMANY	6	
MEGA DALE	LIBERIA	5	
MERCY VENTURE	CANADA	4	
MIMI	NORWAY	1	
MINERVA	NORWAY	3	3
MSC LAUREN	PANAMA	1	
MT CHIPPEWA	LIBERIA	2	
MT PANDA	LIBERIA	2	
MT URZHUM	UKRAINE	1	
MT VARG	NORWAY	1	
NADEZHDA OBUKHOVA	RUSSIA	3	
NAND NEETI	LIBERIA	1	
NAYDIC	NETHERLANDS	1	
NCC TIHAMAH	SAUDI ARABIA	1	
NEDROMA	ALGERIA	5	
NEFTEGAZ 66	RUSSIA	3	
NEW ARGOSY	LIBERIA	1	
NEW VICTORY	LIBERIA	1	1
NEWFOUNDLAND OTTER	CANADA	3	
NORTHERN PRINCESS	CANADA	1	
NORQUEST	NORWAY	2	
NOSAC EXPLORER	NORWAY	2	2
OBO VICTORY	ITALY	1	
OCEAN PRAWN	UNKNOWN	2	
OCEANIC ICE	NETHERLANDS	5	2
OMEGA VENTURE	UNKNOWN	1	
OOCL ASSURANCE	HONG KONG	14	
OOCL BRAVERY	HONG KONG	8	
ORAGREEN	BAHAMAS	1	
ORFEAS	CYPRUS	1	
PABLO NERUDA	LATVIA	1	
PACIFIC LINK	VANUATU	1	
PAL MARINOS	CYPRUS	1	
PANGIOTIS L	GREECE	1	
PATRIOTICOS	CYPRUS	1	
PAUL BUCK	USA	5	2
PAULUBJ	UNKNOWN	1	1

* Sea Surface Temperature

Ship Name	Ship Flag	Ice Report	SST* Report
PERMEKE	LIBERIA	2	
PETROLAB	CANADA	1	
PHOENIX-M	UNKNOWN	3	
PIERRE RADISSON	CANADA	4	
PIONEER STAR	GREECE	7	
PONTOKRATIS	CYPRUS	1	
PRINCESS ARROW	PANAMA	1	
PROUSSA	CYPRUS	1	
RAGNA GORTHON	GREECE	1	
RED TULIP	UNKNOWN	13	
REYKJAFOSS	ICELAND	1	
RHEA	GREECE	3	
RHODOS	GREECE	1	
RIESA	GERMANY	1	
RIO JIBACOA	CUBA	1	
RIXTA OLDENDORFF	GERMANY	3	
ROYAL PRINCESS	UNITED KINGDOM	1	
RUBENE	GERMANY	1	
SACHSEN	GERMANY	1	
SAGA RIVER	NORWAY	3	
SAGA TIDE	JAPAN	1	
SAGA WAVE	NORWAY	1	
SAINT BRICE	FRANCE	1	
SASKATCHEWAN PIONEER	CANADA	19	
SAUNIERE	CANADA	1	
SAVAZA	CZECHOLOVAKIA	3	
SEA BREEZE	NORWAY	14	14
SEA CAVALIER	FRANCE	1	
SEA DANIEL	SWEDEN	5	3
SEA GRACE	PANAMA	4	4
SEA LAND PREFORMANCE	USA	1	
SEA LAND QUALITY	USA	1	
SEALANE	GREECE	1	
SELNES	CYPRUS	4	
SELNES WIND	SWEDEN	1	
SELENES	ICELAND	4	
SERGY KIROV	CYPRUS	1	
SEVERNYX	UKRAINE	1	
SIBONANCY	NORWAY	1	
SIDSEL KNUTSEN	NORWAY	2	
SIR GRENFELL WILFRED	CANADA	3	
SIR JOHN FRANKLIN	CANADA	1	
SKOGAFOSS	ICELAND	9	
STAR OHIO	USA	3	
STASSFURT	GERMANY	8	

* Sea Surface Temperature

Ship Name	Ship Flag	Ice Report	SST* Report
STEEL FLOWER	PANAMA	2	2
STEVENS	JAPAN	2	
STOLT ALLIANCE	PANAMA	1	
STOLT ASPIRATION	PANAMA	2	
STOLT SINCERITY	PANAMA	1	
STORDEN	SWEDEN	1	
STRIGGLA	GREECE	1	
STRONG ICELANDER	USA	12	2
SUDMALIS IMANT	RUSSIA	2	
SULBY	FRANCE	2	
SUN TRADER	NORWAY	2	
SYLVIA LYNN 2	CANADA	1	
TEAM FROSTA	NORWAY	1	
TECHNO VENTURE	CANADA	1	
TEXAS	NORWAY	1	
TOMIS LIBERTY	GREECE	1	
TOKYO REEFER	PANAMA	1	
TOPAZ	UNKNOWN	1	
TORILL KNUTSEN	NORWAY	5	1
TOSCA	SWEDEN	3	
TRANS ARTIC	NORWAY	2	
TULPINAS	UNKNOWN	1	
UNITED V	CYPRUS	1	1
VALGA	ESTONIA	4	
VARJAKKA	FINLAND	1	
VENI	GREECE	1	1
VERTIKALIS	LITHUANIA	2	
VICAL	CYPRUS	1	
VINALES	CUBA	2	
WELLINGTON KENT	CANADA	4	
WESTERN BRIDGE	BAHAMAS	1	
WESTERN EXPRESS	UNKNOWN	1	
ZELENOBORSK	RUSSIA	3	
ZIEMA GNIEZNIENSKA	POLAND	7	4
ZIEMIA TARNOWSKA	POLAND	2	
ZINA	RUSSIA	2	

TOTAL ICE REPORTS 1105

TOTAL SST REPORTS 201

* Sea Surface Temperature

Appendix C

International Ice Patrol's Iceberg Season Severity

Geoffrey Trivers

INTRODUCTION

Throughout its history, International Ice Patrol (and other authors) has struggled to define an "average" iceberg season. Despite the many different possible iceberg-season severity indexes (iceberg population, iceberg season length, iceberg-limit areal extent), the only Ice Patrol index has been iceberg populations south of 48°N.

Most recently, Alfultis (1987) defined four population severity classes (Table 1) based on the entire iceberg record (1900-1987). However, recognizing the various iceberg data collection methods, Ice Patrol Annual Reports have also compared the respective year's iceberg population to averages for the different data collection years (e.g., 1945-1982: aircraft years, 1982-present: Side-Looking Airborne Radar (SLAR)-equipped aircraft years). The recent sole use of the SLAR-years' average implies that the SLAR years' data is more trustworthy than the pre-SLAR years' data, a seemingly reasonable assumption, though tough to quantify. (See Anderson (1993) for an excellent synopsis of the impact of changing Ice Patrol technology on the iceberg counts.)

However, one shouldn't blindly make conclusions on a record as short as the SLAR years. An extreme year under the Alfultis (1987) definition is "average" according to the SLAR-years mean (Table 2). Is this evidence that the pre-SLAR-years population data is undercounted? Or does this mean that the SLAR-years populations are overcounted?

This paper examines the iceberg population data (Figure 1) against high quality sea-ice data in order to redefine the severity definitions and also examines another potential severity index, iceberg season length.

Table 1
Alfultis (1987) Iceberg Population Severity Classes

Light	<300 icebergs south of 48°N
Average or Intermediate	300-600 icebergs south of 48°N
Heavy	601-900 icebergs south of 48°N
Extreme	>900 icebergs south of 48°N

ICEBERG POPULATION SEVERITY

Almost all authors using IIP data have struggled with the non-normal distribution of the population data. Figure 2 shows the frequency distribution of the iceberg populations for the entire record and the SLAR years. In both cases, low populations are the most frequent. Table 2 illustrates this point numerically. In both cases, the median is much lower than the mean. Thus, the average fails to emphasize that the iceberg intensity is most commonly very light. In addition, the standard deviation for the SLAR years is so large that only two data point can be considered statistically greater than the mean. In other words, only two data points can be considered "larger than average". Therefore, these averages are meaningless and comparisons to them should be avoided.

Many authors (Smith (1931), Marko, et al. (1986), Marko et al. (1994)) have shown that sea-ice is a more reliable iceberg population predictor than other environmental indexes (e.g., air temperature, zonal pressure difference). Marko, et al. (1994) found a good correlation between the iceberg count and the Grand Banks sea-ice extent. Intriguingly, they also showed a bilinear response of the iceberg count to the sea-ice extent. In other words, low and high sea-ice years had a differing relationship iceberg count to ice extent. The threshold value for the different responses was associated with an ice extent that placed the outer edge of the ice edge over the core of the Labrador Current. In other words, when the sea-ice limits cover the core of the Labrador Current, iceberg counts increase markedly per unit increase in sea-ice cover. Based on his iceberg-sea ice scatter

Table 2
Mean and Median Iceberg Population Count

	Mean ± Standard Deviation *(# of icebergs)*	Median *(# of icebergs)*
All data (1900-1995)	455±485	312
SLAR years (1983-1994)	1065±743	876

Table 3
Marko, et al. (1994) Iceberg Population Severity Classes

Low	<200 icebergs south of 48°N
Intermidiate	200-600 icebergs south of 48°N
High	>600 icebergs south of 48°N

Table 4
New IIP Iceberg Population Severity Classes

Light	<300 icebergs south of 48°N
Moderate	300-600 icebergs south of 48°N
Extreme	>600 icebergs south of 48°N

plot, Marko, et al. (1994) suggested three iceberg severity classes (See Table 3). Their plot is updated in Figure 3 using revised sea ice data[1].

The good correlation coefficients between sea ice and iceberg populations (Figure 3) highly suggest that, with few exceptions, the iceberg counts since 1963 are reasonable. The one notable exception is 1984, a year suspected to be greatly overestimated because of Ice Patrol's inexperience with a new sensor (Thayer (1984)). The good correlations suggest that the quality of the data is relatively consistent between the two eras. This is another reason not to make conclusions on an era average.

The bilinear response in the iceberg-sea ice scatter plot and the good correlation validates the Marko, et al. (1994) iceberg severity classes. Their definitions are very close to the Alfultis (1987) definitions except for the greater-than-900 class. There is no evidence of a fourth category in this correlation. The population severity definitions suggested by Figure 3 are contained in Table 4.

Table 5
IIP Ice Season Length
Severity Classes

Short	<105 days
Average	105-180 days
Long	>180 days

The slight disagreement between the Table 3 and 4 lower thresholds is due to slightly different sea-ice data. Figure 3 suggests that the lower (light) threshold is between 200 and 500. A threshold of 300 was chosen for consistency with Alfultis (1988). The purposeful use of term "moderate" was to avoid any connection to the terms "mean" or "average".

ICEBERG SEASON LENGTH SEVERITY

A severity index that has not been previously investigated is the length of the ice season. This is roughly the amount of time that icebergs are present south of 48°N. The season length correlates well (r=0.7) with sea-

[1] Marko's (1994) correlation looks slightly different due to a different sea-ice data. Marko used tha ice extent in three different bands 45°-47°N, 49°-51°N and 53°-55°N as estimated from Prisenberg and Peterson (1990). I used the entire ice extent from 45° to 55°N.

ice extent (Figure 4). This result was expected a priori, although the good level of correlation was unexpected.

Because the season length distribution is nearly normal (Figure 5) and correlates well with another environmental index, the season length average (140 days) and standard deviation (35 days) are meaningful. Therefore, I have defined an "average" ice season length as the mean plus or minus one standard deviation (Table 5).

CONCLUSION

Despite concerns over changing technology impacting the iceberg counts, high-quality sea-ice data has validated most of the recent IIP iceberg populations. With one exception, the SLAR year's populations do not appear to be significantly overcounted. Conversely, the pre-SLAR year's data does not appear to be undercounted.

Based on the sea-ice correlation, I presented iceberg population severity classes (Table 4). Similarly, the iceberg season length correlated well with the sea-ice extents and, as such, seems to be a believable index. Based on the near-normal distribution, ice season length severity classes are presented in Table 5.

Annual Counts of Icebergs Crossing 48° North Latitude (1912-94)

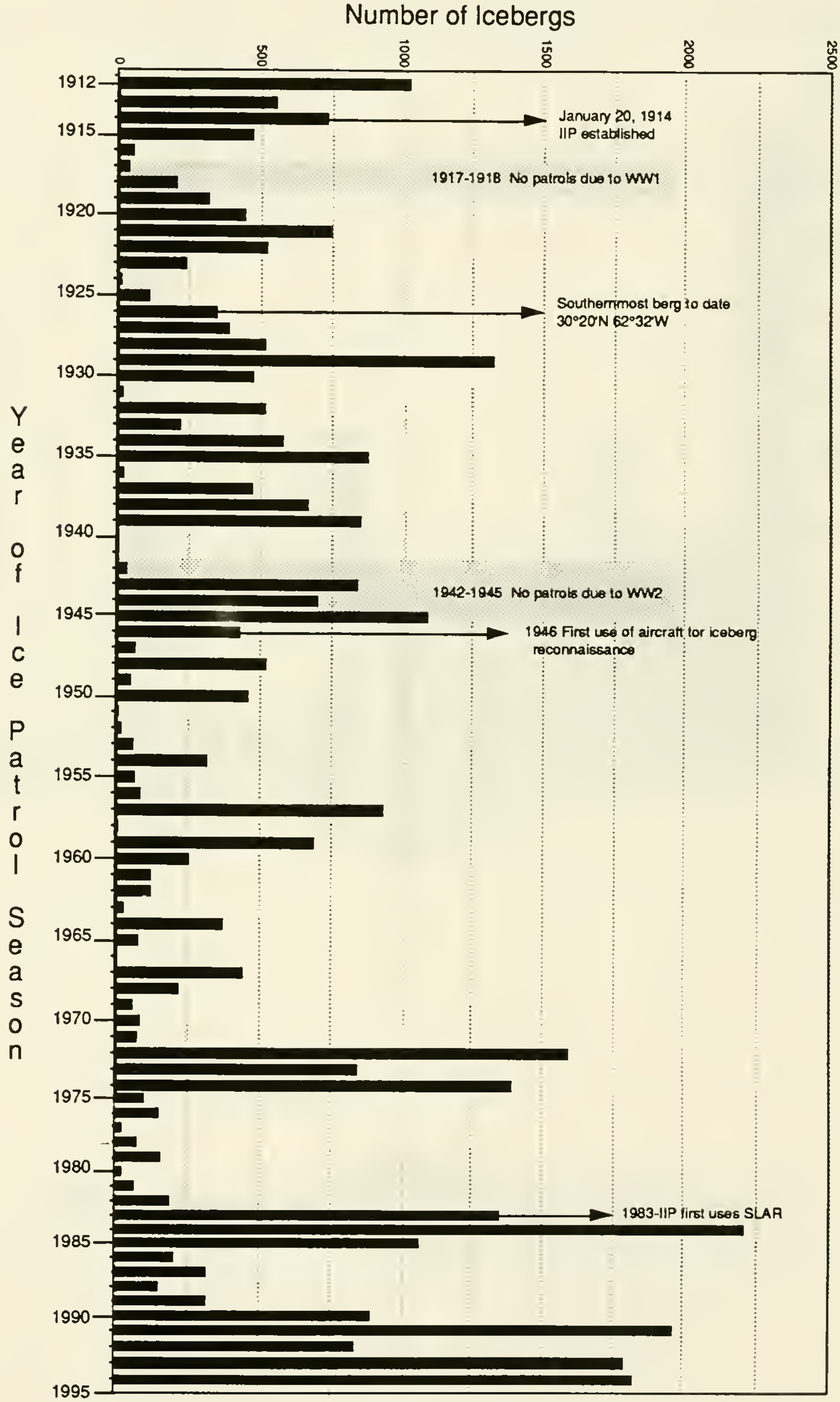

Figure 1

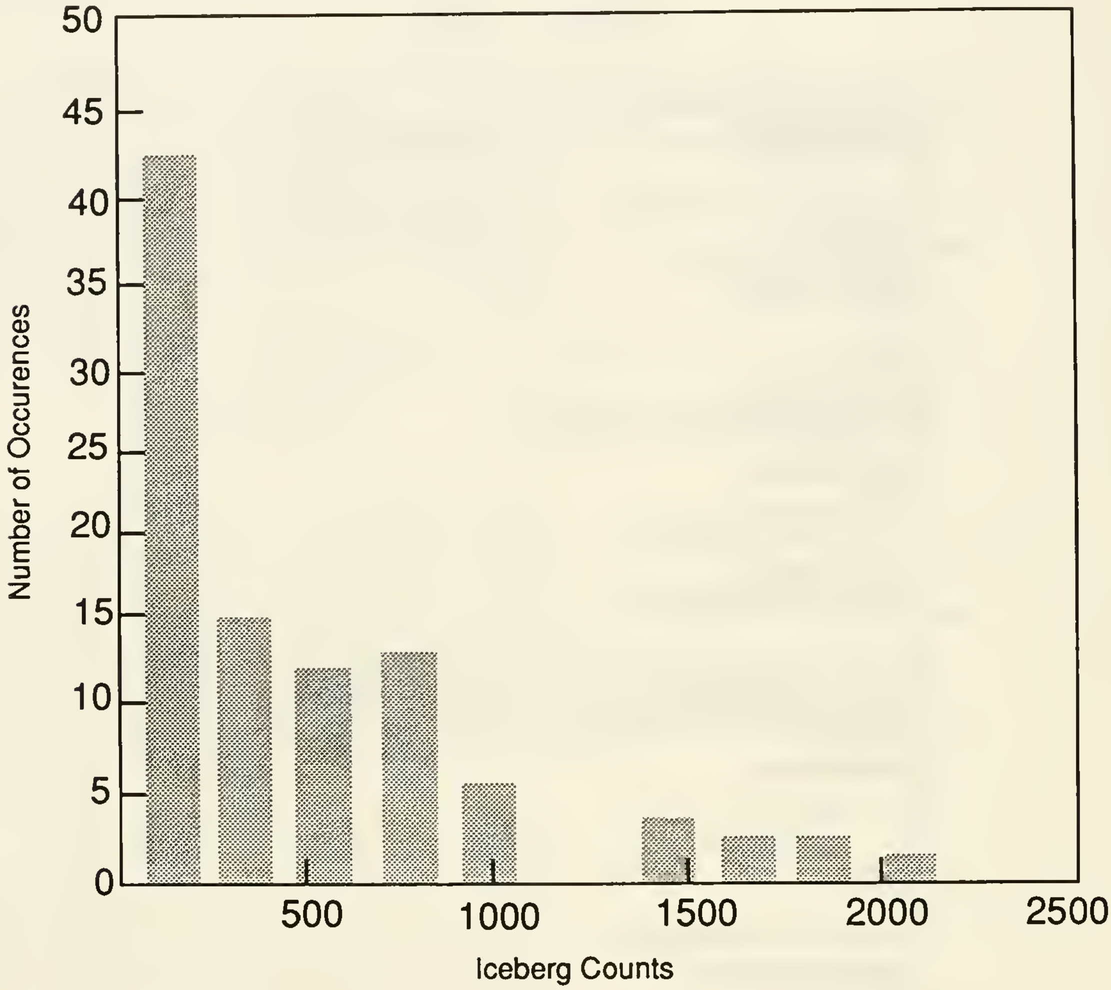

Figure 2 (a)
Frequency distribution of iceberg population for (1900-1993).

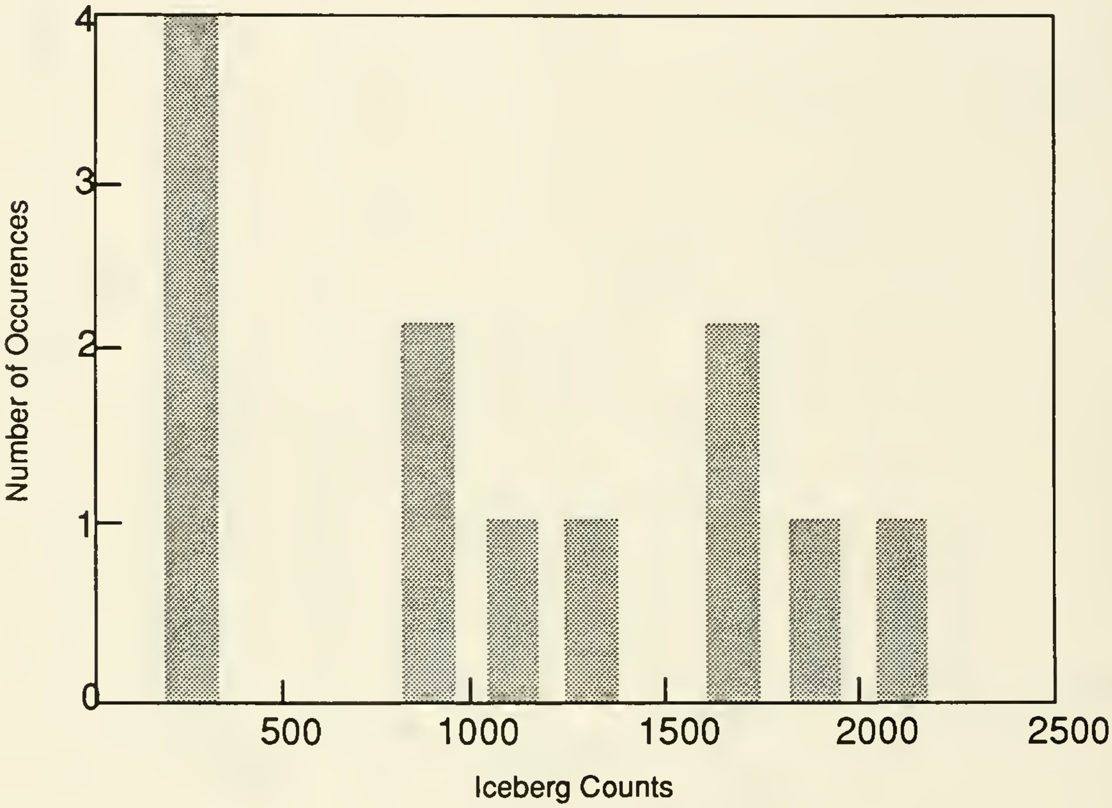

Figure 2 (b)
Frequency distribution of iceberg population for SLAR years (1984-1993).

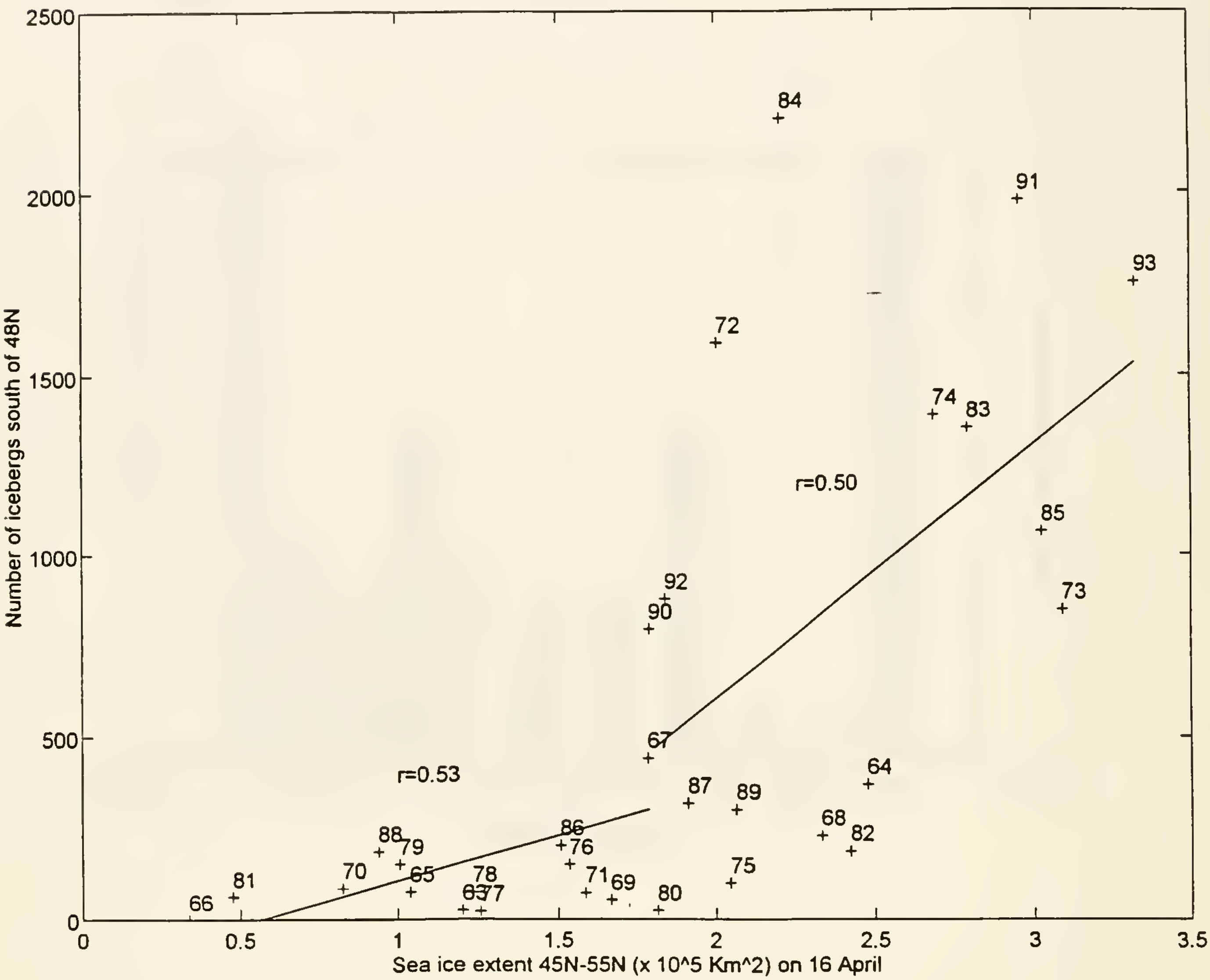

Figure 3

Plot of iceberg populations versus 16 April sea-ice extent east of Newfoundland (45°-55°N) for period 1963-1993. High quality sea ice data is not available for periods prior to 1963. The sea-ice extent data was kindly supplied by Ms. Ingrid Peterson of Bedford Institute of Oceanography.

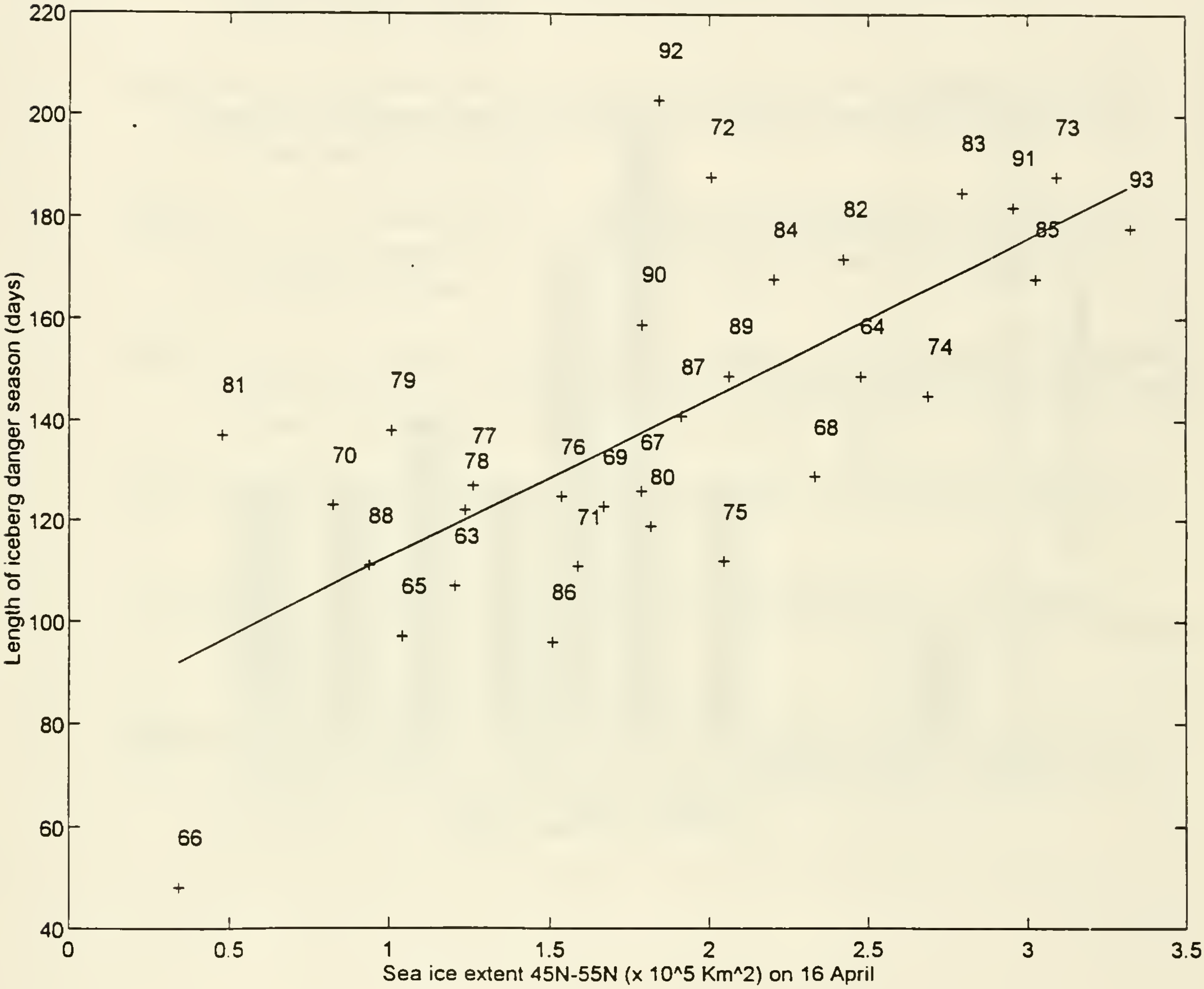

Figure 4
Plot of iceberg season length versus 16 April sea-ice extent east of Newfoundland (45°-55°N).

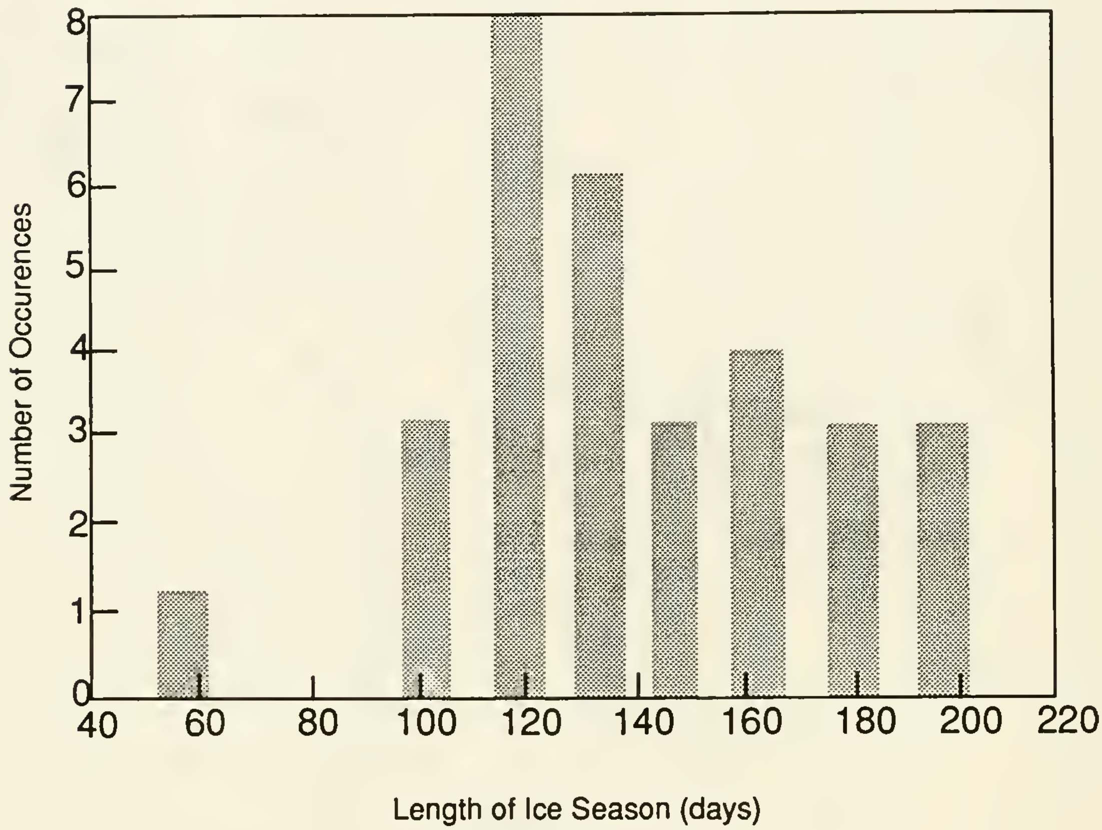

Figure 5
Frequency distribution of iceberg season length for entire record (1963-1993).

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Appendix D

The Intergration of Forward-Looking Airborne Radar into the International Ice Patrol's Sensor Suite

by Geoffrey A. Trivers and Donald L. Murphy

ABSTRACT

International Ice Patrol (IIP) monitors and broadcasts the southeastern, southern, and southwestern limits of icebergs in the vicinity of the Grand Banks of Newfoundland. Because of the chronically foggy conditions over the Grand Banks, IIP relies almost exclusively on radar aboard USCG HC-130H aircraft for iceberg reconnaissance. Since 1983, IIP's primary detection radar has been the AN/APS-135, Side-Looking Airborne Radar (SLAR). In 1993, IIP added the AN/APS-137, Forward-Looking Airborne Radar (FLAR) as an additional sensor. Our operational experience and two tests (1991 and 1993) have shown that the strength of the FLAR is its ability to distinguish between icebergs and ships. However, the field tests showed that in some cases the FLAR failed to detect small and medium icebergs (50 m and 100 m long, respectively) at ranges at which the SLAR routinely detects targets. Therefore, to avoid the smaller geographic coverage of a FLAR-only equipped aircraft, the two radars are used in combination, providing IIP with an greatly improved sensor suite for iceberg reconnaissance.

INTRODUCTION

International Ice Patrol's primary mission is to determine and guard the southern, southeastern, and southwestern limits of all known ice in the vicinity of the Grand Banks of Newfoundland. This service is provided to transatlantic shipping by the U.S. Coast Guard, as required by International Safety of Life At Sea (SOLAS) Convention and 46 USC 738, in response to the tragic sinking of the RMS TITANIC on 15 April 1912.

Ice Patrol seeks to track all icebergs reported in the western North Atlantic Ocean and warns mariners of the extent of the threat icebergs pose to safe navigation. This task is a large scale problem, both spatially and temporally. The Ice Patrol operating area extends from 40°N to 52°N and 39°W to 57°W. During a typical iceberg season, which extends from March through July, approximately 300-600 icebergs pass south of 48°N, below which icebergs are considered to be threats to trans-oceanic shipping.

Ice Patrol receives iceberg reports from a variety of sources, including commercial shipping and aerial reconnaissance supported by several Canadian government agencies and private industry. Ice Patrol's own aerial reconnaissance accounts for about one-third of the icebergs detected during a season. However, the importance of Ice Patrol's aerial reconnaissance exceeds that suggested by these simple statistics. Because Ice Patrol's intent is to define the limits as accurately as possible, neither underestimating nor overestimating the extent of the threat, its reconnaissance effort focuses on icebergs that define the boundaries. Thus, the Ice Patrol aircraft usually operates in areas of low iceberg density. The ability of the Ice Patrol aircraft to detect and identify icebergs is critical to the success of the mission.

Near the Grand Banks, the extraordinarily poor visibility caused by the convergence of the cold Labrador Current and the

warm Gulf Stream in the region adversely affects ship and aircraft operations. For ships, the combination of bad visibility and the proximity of icebergs creates an obvious hazard to safe navigation. Less obvious is the severe limitation poor visibility places on aircraft reconnaissance. Indeed, conditions suitable for visual reconnaissance are rare. During the iceberg season, the cloud ceiling on the northern Grand Banks is less than 1000 ft. or visibility less than 2.5 nm roughly half the time (Mortsch et al., 1985). During the period from 1948 through 1982, when Ice Patrol relied on aerial visual reconnaissance, an aircraft was stationed in Newfoundland, Canada for the entire iceberg season. Patrols were flown when and where visibility conditions permitted. To maximize reconnaissance opportunities in such poor visibility conditions, Ice Patrol sought new airborne remote sensing technologies able to detect and identify icebergs.

SLAR RECONNAISSANCE

In 1983, Ice Patrol began to use the AN/APS-135, Side-Looking Airborne Radar (SLAR), an X-band (9250 MHz), real aperture surveillance radar manufactured by Motorola. It was acquired by the Coast Guard primarily for the task of locating and tracking oil spills, however, its usefulness to the Ice Patrol mission was clear. The SLAR imagery is produced on 9 in. dry process photographic film. The image is not visible to the operator in real time; the processing time is about five minutes. Gridded film is the only georegistration. Field studies (Robe et al, 1985; Alfultis et al, 1988; and Rossiter, et al., 1985) have shown the SLAR to be an effective iceberg (>15 m long) detector at typical Ice Patrol search altitudes (6000-8000 ft)[1]. The ability to detect smaller pieces of ice such as growlers (<15 m) seems to be strongly dependent on sea state; the larger the seas, the less likely that a growler will be seen by the SLAR. How effective the SLAR is at discriminating between icebergs and vessels is not as well known.

In the absence of visual confirmation there are several ways to infer whether a SLAR radar target is an iceberg or a vessel. The best cue is gross target movement. If the target is moving at significant speed (>10 kts), it is clearly a ship. The presence of ship's wake can sometimes be detected by radar, also indicating the target is a ship. Radar shadows (an area of no radar return on the side away from the radar) can sometimes be used to suggest that the target is a relatively tall target, and therefore more likely to be an iceberg. Finally, the intensity of the radar return is used to add to the evidence that a target is a ship. "Hard" targets are more likely to be ships.

Other than gross target movement, none of the cues are very compelling and are dependent on the experience of the film interpreter. Target identification with SLAR is somewhat of an art, and the ice observers are left with many ambiguous targets. The many stationary fishing vessels in the Grand Banks present severe identification problems. Their small size and lack of substantial motion make them difficult to differentiate from icebergs.

[1] Because of the chronically low-visibility conditions over the Grand Banks, the Coast Guard desires to fly in controlled airspace. In international oceanic airspace, 5500 ft is the lowest controlled flight level. This altitude range (6000-8000 ft) has proven to optimize visual and radar detection.

Classifying SLAR-detected icebergs according to size cannot be done with much confidence.

Ice Patrol's reconnaissance strategy was designed to take maximum advantage of the SLAR's all-weather capability, while at the same time, recognizing its detection and target discrimination uncertainties. Ice Patrol searches for icebergs using USCG HC-130H long range surveillance aircraft operating out of St. John's, Newfoundland, Canada for seven days every other week. It takes approximately four flight days to investigate a 120 nm swath along the entire limits of all known ice. Daily patrols are conducted using a parallel search pattern with track spacing of 25 nm and the SLAR range scale set at 27 nm. Thus, the SLAR gets two looks at most of the search area. The 200% coverage seeks to ensure that no growlers or small icebergs are missed and to get target movement information (course and speed for ships), which can be determined by the target's displacement between successive search legs.

The addition of the SLAR tremendously improved Ice Patrol's reconnasaince efficiency. After the addition of the SLAR, Ice Patrol was able to get the same amount of patrols in a week as two weeks without the SLAR. SLAR target identification remained problematic. Targets on the outside of the airplane's track are an identification problem as the radar sweeps this area once and the SLAR operator is unable to deduce any drift information. This outside area is typically one third of the total search area.

FLAR

When the Coast Guard began evaluating the AN/APS-137 Forward-Looking Airborne Radar (FLAR) as a search and rescue target detector, Ice Patrol recognized its potential to detect and identify icebergs. The FLAR, which was developed by Texas Instruments to detect small targets in high sea states, is an X-band air-to-surface radar capable of Inverse Synthetic Aperture Radar (ISAR) mode and seemed ideally suited for the Ice Patrol environment. It is a high power radar that combines long-range detection and target imaging capabilities into a single, integrated system.

The AN/APS-137 has four operating modes, three of which are variations of a surface search mode (search, navigate, and periscope), and an imaging mode. In the surface search modes, the radar uses a real aperture, while the imaging mode is ISAR.

The following is a brief summary of the individual modes:

1. Search mode: designed for wide-area searches.

2. Periscope mode: designed for shorter range, low altitude (<3000 ft) searches for small targets. The high antenna scan rate, the radar pulse frequency and duration, and sophisticated data processing permit reduction in sea clutter and an amplification of small target return.

3. Navigate mode: wide-area search, but low antenna scan rate, which is suitable for navigation and can be used for target detection.

4. Imaging mode: The ISAR is a synthetic aperture radar (SAR) that takes advantage of the rotation of the target, rather than the movement of the aircraft. In the imaging mode, the radar's antenna stops rotating and directs its radar beam at the target. While imaging, the radar processes only range data, generating a range versus Doppler display. The information is then converted into a

video signal which shows the target outline and prominent features, such as king posts, exhaust stacks, etc. For a target to be imaged it must have first been detected in a surface search mode, as the imaging mode does not operate independently of the other modes.

The FLAR automatically tracks targets, and calculates target course and speed. This automatic process is far superior to the manual method of determining the location and movement of targets using the grid lines on the SLAR film. However, this process is affected by position errors from the aircraft's inertial navigation system (INS). The planned implementation of the global positioning system (GPS) navigation will substitutionally improve the accuracy of course and speed estimates.

In 1991 and 1993, Ice Patrol conducted two tests of the FLAR's ability to detect icebergs (Ezman et al, 1993; and Trivers and Murphy, 1994). Both tests focused solely on the FLAR navigate mode. These tests indicated that the FLAR failed to detect small and medium icebergs at ranges the SLAR has shown a high probability of detection. Presumably this is due to the head-on nature of the FLAR. O'Brien et al. (1993) demonstrated that the best life-raft detection performance for FLAR was between 350 and 010°R and that the performance dropped off significantly at relative bearings of greater than ±045°R. All the data reported in O'Brien et al. (1993) were collected with the radar in the periscope mode and at altitudes (500 and 1500 ft) much lower than Ice Patrol altitudes.

Trivers and Murphy (1994) indicated a slight increase in FLAR iceberg-detection range with altitude and hinted at a decrease in iceberg detection-range with sea state.

In a test with HU-25 radars (AN/APS-127 FLAR and AN/APS-131 SLAR), Lewandowski et al. (1989) computed much smaller FLAR-only liferaft sweep widths than SLAR-only liferaft sweep widths. This result and HC-130 FLAR work all seem to indicate that FLAR is far less efficient at poor radar-reflective target detection. Presumably, this is due in part to the spreading of FLAR power over a much larger beamwidth. The AN/APS-135 SLAR has twice as much peak power to azimuthal beamwidth as the AN/APS-137 FLAR. The multiple "looks" of the FLAR does not do much good if the radar cannot generate enough power to get a return signal.

However, Ezman et al (1993), Trivers and Murphy (1994), and operational experience demonstrated that the FLAR is a very strong discriminator, especially between iceberg and ship. No attempt was made to test the ability of the FLAR to discriminate between various sizes of icebergs.

Currently, the radar operators have limited experience in imaging icebergs, although they have much more experience in imaging vessels. Stationary small fishing vessel identification remains problematic even with FLAR because of their small target area, their lack of true motion, and their vertical motion that mimics the wave motion. Much more work needs to be done on gaining FLAR identification experience. This would require clear conditions (or surface truth) for operator training feedback.

COMBINED FLAR/SLAR OPERATIONS

Ice Patrol could rely solely on FLAR-equipped aircraft, using a as yet, undetermined smaller track spacing than the current 25 nm spacing. However, a 15 nm track spacing would result in a 40% reduction in search area. This smaller track spacing would add an extra search day per biweekly period to cover the entire limits of all known ice.

To avoid the added time and expense of a FLAR-only aircraft, Ice Patrol has combined the FLAR and SLAR in our operations.

Figure 1 shows a typical Ice Patrol search pattern. The same track spacing as SLAR-only operations is used to continue to take maximum advantage of SLAR detection capabilities. Essentially, Ice Patrol relies on the SLAR (and the FLAR search mode to a lesser extent) for wide-area searching and tries to identify as many targets as possible with the FLAR imaging mode.

Currently, the two radars are operated independently. The FLAR and SLAR radar repeaters are located next to each other in the cargo compartment of the HC-130, allowing for easy cross comparison once the SLAR image is processed.

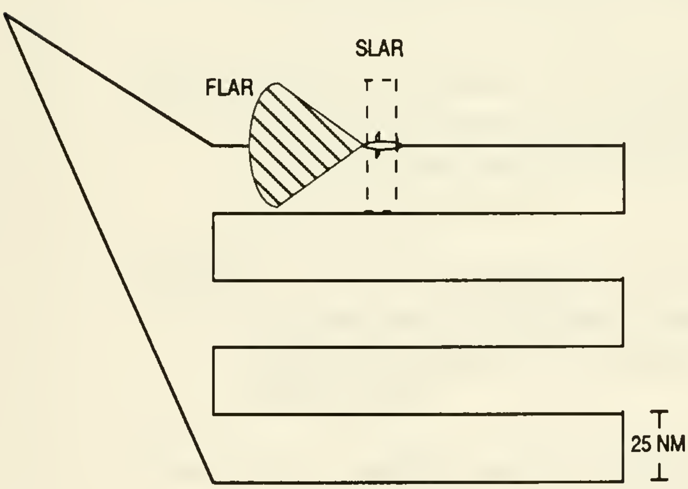

Figure 1
Schematic showing typical IIP parallel search pattern. Dashed lines indicate FLAR/SLAR search areas.

This combination has been very successful. Table 1 shows the significant decrease in unidentified targets after the FLAR was integrated into IIP operations at the beginning of the 1993 ice season. (Ice Patrol flies approximately 65 reconnaissance flights during a typical ice season.) An unidentified target is one not positively identified as either an iceberg or a ship. This 50% reduction in unknown targets directly translates into a higher quality Ice Patrol product, as Ice Patrol defines the ice limits around positively identified icebergs.

CONCLUSION

The AN/APS-137 FLAR has proven to be a valuable addition to the combined AN/APS-135 SLAR/ "visual" sensor suite. This radar does not replace the SLAR for iceberg detection, but its identification ability has significantly improved Ice Patrol's ability to identify targets and has made Ice Patrol's iceberg danger warnings more accurate.

The two radars are not fully integrated as no radar data logging system is installed in the aircraft. The SLAR data time delay makes real time intercomparison difficult. The Coast Guard is planning to upgrade SLAR to make it a digital real-time system. This is expected to improve the range resolution and significantly improve the georegistration. There are no

Table 1
Average Number of Unidentified Targets per Reconnaissance Flight

Ice Season	Unidentified Targets/Flight
1991	3.5
1992	3.6
1993	1.8
1994	1.0

plans for full integration of the two systems. The digital integration of the FLAR and the SLAR could provide substantial improvement in the Ice Patrol's reconnaissance performance.

Ice Patrol will greatly benefit by gaining further experience in detecting and identifying icebergs.

Ice Patrol's present use of the combined SLAR and FLAR system is appropriate for the large spatial and temporal scale mission. However, FLAR has some features which might make it useful for other ice detection missions. For example, the FLAR periscope mode seems likely to be very useful for smaller-scale glacial ice detection in the future such as may be required to support specific ship routing. However, much more work is needed to define probability of iceberg detections as a function of search altitude, weather conditions, and sea state.

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